DIY Off-Grid Solar System V2.0

by opengreenenergy

The prices of solar panels have been falling gradually but the cost of an off-grid solar system setup is rising steadily. However, anyone with basic knowledge of Electricity and having a toolbox can install it on their own. This will reduce the overall system cost substantially and you will learn a lot.

In order to build a basic off-grid solar system, you will need the following components:

1. Solar panel
2. Charge Controller
3. Battery
4. Inverter
5. Balance Of System (Cable, Breaker, Meter, Fuses, and MC4 connectors)

In this Instructable, I will guide you step-by-step on how to choose the appropriate components of your Off-Grid Solar System and then guide you on how to connect and set them up properly.

- Follow me on Instagram @opengreenenergy
- You can find all of my projects on https://www.opengreenenergy.com/

Full Video Tutorial:

//www.youtube.com/embed/X_0AecD6E1M

Supplies:

Components Required :

1. Solar Panel (Amazon / Solar Panel)
2. Charge Controller (Amazon / Aliexpress)
3. Battery (Amazon)
4. Inverter (Amazon / Aliexpress)
5. Remote Meter (Amazon / Aliexpress)
6. WiFi Adapter (Aliexpress)
7. Temperature Sensor (Amazon / Aliexpress)
8. DC Breaker (Amazon / Banggood / Aliexpress)
9. AC Breaker (Amazon / Aliexpress / Banggood)
10. DC Busbar (Amazon / Aliexpress / Banggood)
11. Fuse Box (Amazon / Aliexpress / Banggood)

12. DIN Rail (Amazon / Aliexpress)

13. Cables (Amazon / Banggood / Aliexpress)

14. MC4 Connector (Amazon / Aliexpress / Banggood)

15. Terminal Lugs (Amazon / Aliexpress / Banggood)

16. Cable Tie (Amazon / Aliexpress / Banggood)

Tools Required :

1. Wire Stripper (Amazon / Aliexpress / Banggood)

2. Crimping Tool (Amazon / Aliexpress / Banggood)

3. Plier (Amazon / Aliexpress)

4. Screwdriver (Amazon / Aliexpress / Banggood)

5. MC4 Spanner (Amazon / Aliexpress / Banggood)

6. Spanners (Amazon / Banggood / Aliexpress)

Step 1: How It Works ?

The off-grid solar system means you are not connected in any way to the utility grid. The system utilizes batteries to store energy produced from solar panels.

Solar Panel:

The solar panel converts sunlight into electricity. Photovoltaic cells on the solar panel absorb the sun’s energy and convert it to DC electricity.

Charge Controller:

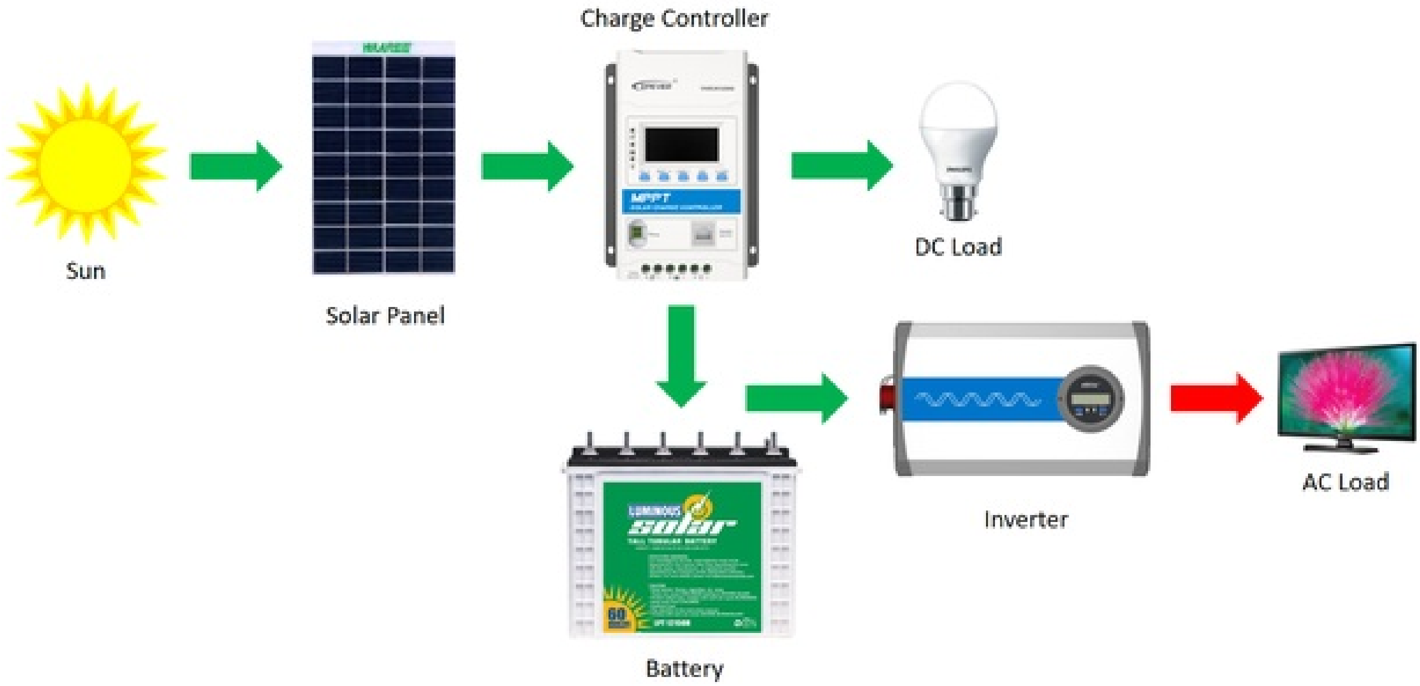
The current from the solar panel feeds into a charge controller, which controls how much current goes to a battery. Charge controllers prevent batteries from being over-charged and over-discharged.

Battery:

It stores energy generated from the solar panel during the day.

Inverter:

It converts the DC (Direct Current) power from the battery bank or solar panels to AC (Alternating Current) so that you can run your AC appliances, such as TV, Fan, Fridge, Water Pump, etc.



Step 2: Basic Electricity Rules

Ohms Law Relationship

Current (I) = Voltage (V) / Resistance (R)

It is easier to remember the Ohms law relationship by using the above picture (Ohms Triangle). By knowing any two values of the Voltage, Current, or Resistance quantities we can use Ohms Law to find the third missing value.

Voltage (V) :

V (volts) = I (amps) x R (Ω)

Current (I) :

I (amps) = V (volts) / R (Ω)

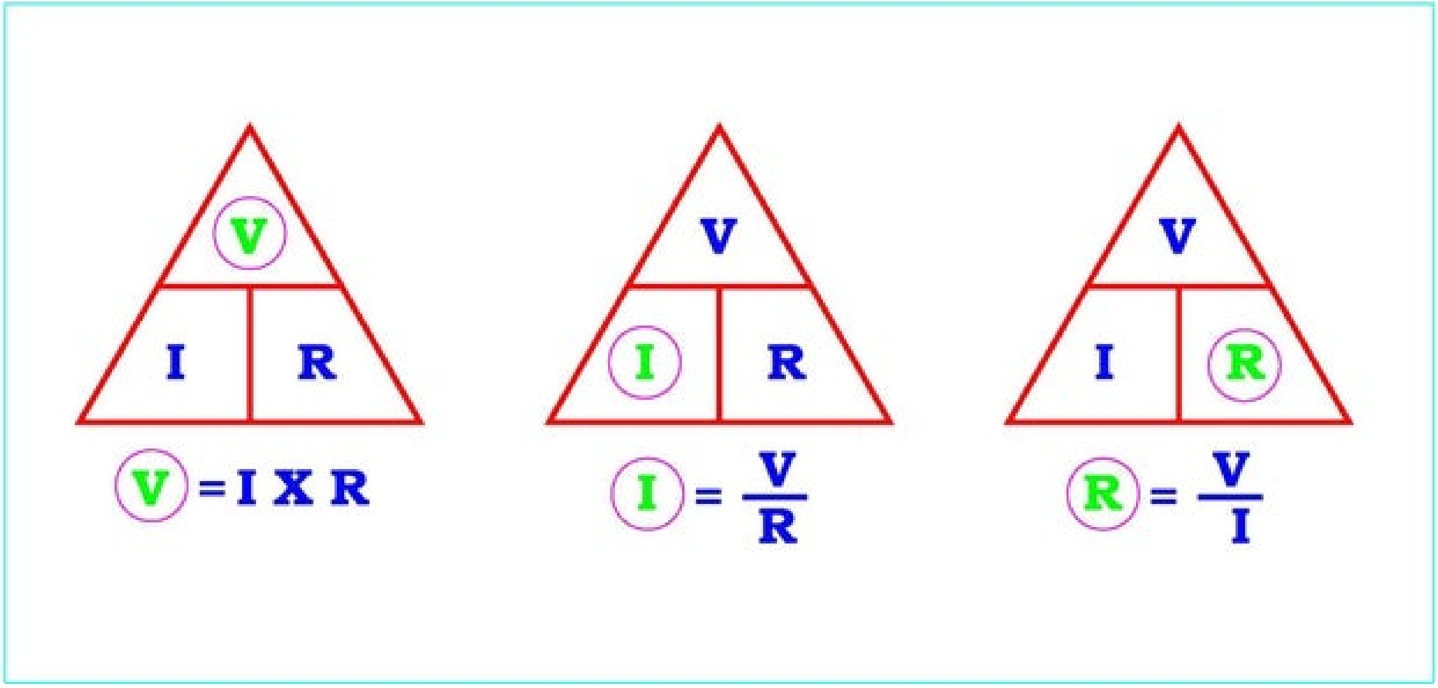
Resistance (R) :

R (Ω) = V (volts) / I (amps)

Power (Watt) = Voltage (Volt) x Current (Amp)

Energy (Watt-hours) = Power (Watts) × Time (Hours)

Capacity = Current (Amp) x Time (Hours)



Step 3: 6 Steps of DIY Off-Grid Solar

The following 6 steps are required for building a DIY Off-Grid Solar System:

1. Calculate Daily Energy Consumption
2. Select the Battery
3. Select the Solar Panel
4. Select Charge Controller
5. Select Inverter
6. Balance of System (BOS)

In the next steps, we will discuss in detail the above points.

Step 4: Calculate Your Daily Energy Consumption

Figuring out your daily energy consumption (Watt-Hours) is the first step for designing an off-grid solar system.

Energy Consumption (Watt-Hours) = Power (Watts) × Time (Hours)

You can get the power rating from the power label (Name Plate) of the appliance or you can measure the actual power consumption by using a wattmeter. I have used my wattmeter to measure the power consumption of a few appliances.

Manual Calculation:

If you're running a 2 Nos of 6W LED bulb for 5 hours a day, 1 No of Fan (80W) for 4 hours, 1 No of Laptop (65W) for 3 hrs, and a WiFi Router (6W) for 24 hours.

1. LED Bulb: 2 x 6W x 5 hr = 60WH
2. LED TV: 1 x 65W x 3 hr = 195WH

3. Ceiling Fan: 1 x 80W x 4 hr = 320WH

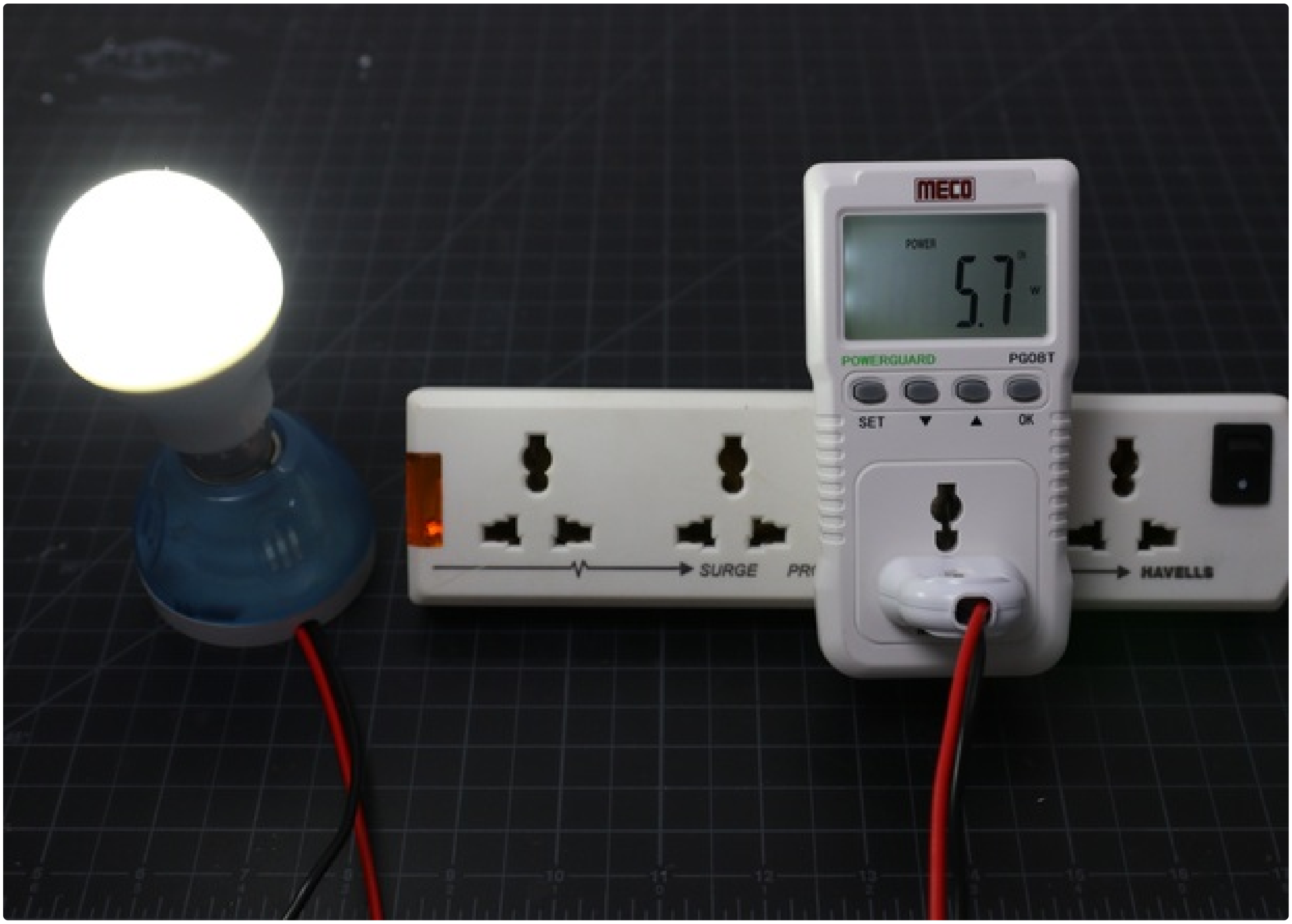
4. WiFi Router: 1 x 6W x 24 hr = 144WH

Total = 719WH

You can calculate the energy consumption manually as shown above or use an Online Calculator


MECO
374.3
POWERGUARD
PG08T
SET
OK
SURGE PROTECTED
BLACK&
DECKER


MECO
POWER
65.0
W
POWERGUARD
PGDBT
SET
OK


MECO
POWER
5.7
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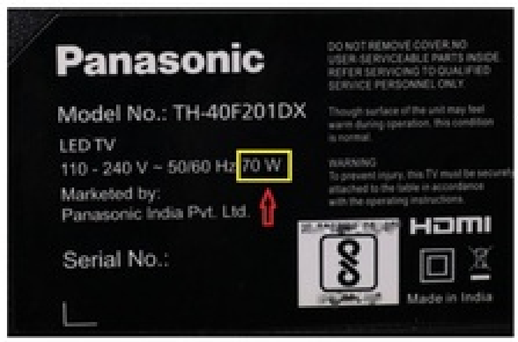
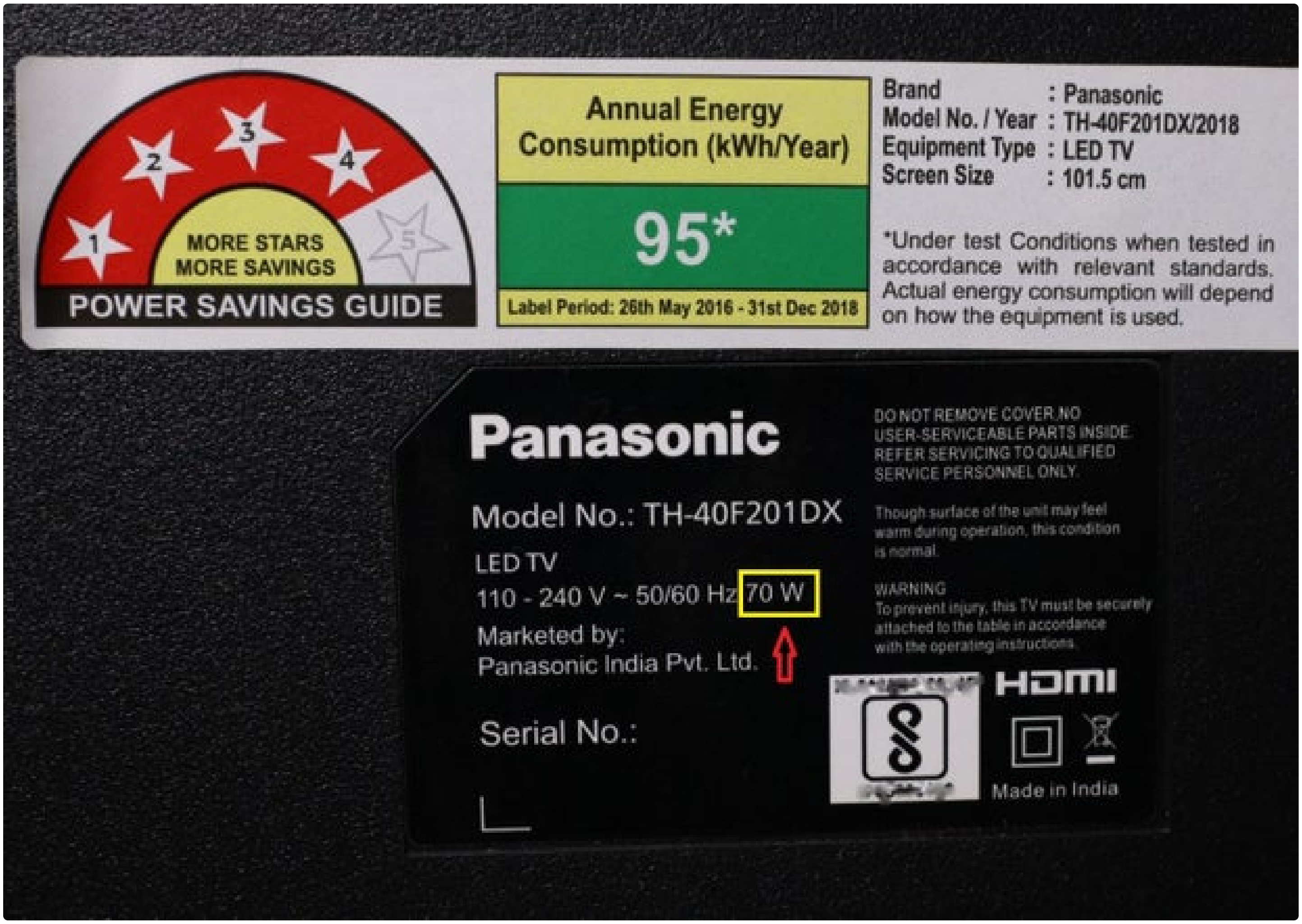
PG08T
SET
OK
SURGE
HAVELLS

Name Plate Rating

Power = 70W




POWER SAVINGS GUIDE
MORE STARS
MORE SAVINGS
Annual Energy Consumption (kWh/Year)
95*
Label Period: 26th May 2016 - 31st Dec 2018
Brand : Panasonic
Model No. / Year : TH-40F201DX/2018
Equipment Type : LED TV
Screen Size : 101.5 cm
*Under test Conditions when tested in accordance with relevant standards. Actual energy consumption will depend on how the equipment is used.
Panasonic
Model No.: TH-40F201DX
LED TV
110 - 240 V ~ 50/60 Hz 70 W
Marketed by:
Panasonic India Pvt. Ltd.
Serial No.:
DO NOT REMOVE COVER.NO USER-SERVICEABLE PARTS INSIDE. REFER SERVICING TO QUALIFIED SERVICE PERSONNEL ONLY.
Though surface of the unit may feel warm during operation, this condition is normal.
WARNING
To prevent injury, this TV must be securely attached to the table in accordance with the operating instructions.
HDMI
Made in India

Step-1: Daily Energy Consumption

SL No	Load	Load Name	Wattage	Quantity	Total Watt	Hour	Watt-Hr
1		LED Bulb	6	2	12	5	60
2		Laptop	65	1	65	3	195
3		Ceiling Fan	80	1	80	4	320
4		WiFi Router	6	1	6	24	144
				Total =	163		719

Step 5: Select the Battery

The battery is used to store the energy produce by the Solar Panel during the day. It is an essential part of an off-grid solar system, and provide a constant source of stable and reliable power that allows to power devices when the sun is down.

The cost of the battery is contributing a large portion of the entire project cost. here we will discuss in detail so that you can select the right battery for your off-grid solar installation.

Batteries are categorized according to 1. Application & Construction 2. Chemistry

1. Applications: Automotive and Deep-Cycle

2. Chemistry: Lead Acid, Lithium, and NiCd

Automotive Battery:

This type of battery is designed to provide a very large amount of current for a short period of time. This surge of current is needed to turn the engine over during starting. Therefore lots of thin plates are employed to achieve maximum surface area and as a result higher starting current in starting batteries.

Application: Automobiles (Car & Bike)

Deep-Cycle Battery:

A deep cycle battery is designed to provide a steady amount of current over a long period of time. This type of battery is also designed to be deeply discharged over and over again. To accomplish this, a deep cycle battery uses thicker plates. This will lead to lower surfaces and accordingly less instant power, unlike the starting batteries.

Automotive Battery

Deep Cycle Battery

Step 6: Lead-Acid Battery Vs Lithium-Ion Battery

Two of the most common battery chemistry types are lithium-ion and lead-acid. Apart from these NiCd is also used for the renewable application, but here I will discuss only the first two.

Lead-acid batteries are made with lead, while Lithium batteries are made with the metal lithium. Lithium and lead-acid batteries can both store energy effectively, but each has unique advantages and drawbacks.

1. Lead-acid Battery:

The lead-acid battery is a tried-and-true technology that costs less, but requires regular maintenance and doesn't last as long.

Flooded Lead-Acid (FLA) :

These types of batteries are submerged in water. These must be checked regularly and refilled every 1-3 months to keep them working properly. It also needs to be installed in a ventilated place to allow battery gases to escape.

Sealed Lead-Acid (SLA):

SLA batteries come in two types, AGM (Absorbent Glass Mat) and Gel, which have many similar properties. They require little to no maintenance and are spill-proof. The key difference in AGM vs. gel batteries is that gel batteries tend to have lower charge rates and output. Gel batteries generally can't handle as much charge current, which means they take longer to recharge and output less power.

2. Lithium Battery:

Lithium is a premium battery technology with a longer lifespan and higher efficiency, but you'll pay more money for the boost in performance.

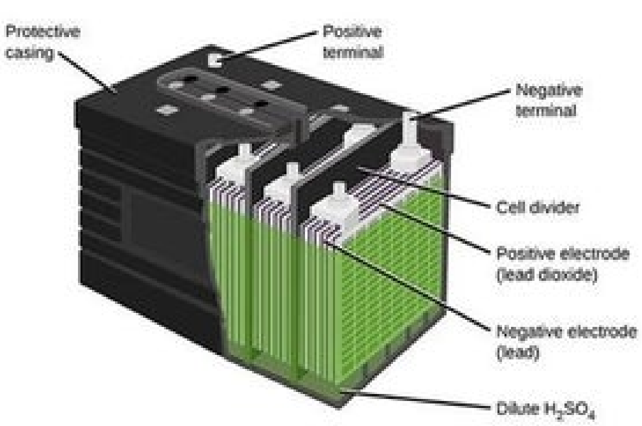
The Lithium batteries that are employed in solar systems are Lithium Iron Phosphate (LiFePO4) which have great thermal stability, high current ratings, and a long life cycle. This new technology lasts longer and can be put through deeper cycles. They also require no maintenance or venting, unlike lead-acid batteries. The main downside for lithium batteries is their higher price compared to lead-acid batteries at the moment.

Which Battery Should You Choose?

If you need a battery backup system, both lead-acid and lithium-ion batteries can be effective options. However, it's usually the right decision to install a lithium-ion battery given the many advantages of the technology – longer lifetime, higher efficiencies, and higher energy density.

If you are planning to live off the grid full-time, you should go with Flooded Lead Acid (if you don't mind regular maintenance) or the premium Lithium option for heavy use.

If you want to install the solar in a small cabin or a vacation home, you'll only be there a few times a year. In this case, you won't be able to provide the regular maintenance which is required for Flooded Lead-acid batteries. Then, I will recommend spending some extra amount to buy a Sealed Lead Acid battery instead.



Lead Acid Battery

Lithium Battery

Step 7: Factors Determine the Battery Bank Size

The following factors determine the battery bank size:

1. Daily power consumption

2. System voltage (12V / 24V /48V)

3. Depth of Discharge (DOD)

In the previous step, we have already calculated the daily power consumption. In the next few steps, we will learn more details above factors.

Step-1: Daily Energy Consumption

SL No	Load	Load Name	Wattage	Quantity	Total Watt	Hour	Watt-Hr
1		LED Bulb	6	2	12	5	60
2		Laptop	65	1	65	3	195
3		Ceiling Fan	80	1	80	4	320
4		WiFi Router	6	1	6	24	144
				Total =	163		719

Step 8: System Voltage

A battery is recognized with its voltage (V) and capacity measured by amp-hours (AH). To provide the desired system voltage, one can wire the batteries in series and parallel.

Series Connection:

Connecting batteries in series add the voltage of the two batteries, but it keeps the same amperage rating (also known as Amp-Hours).

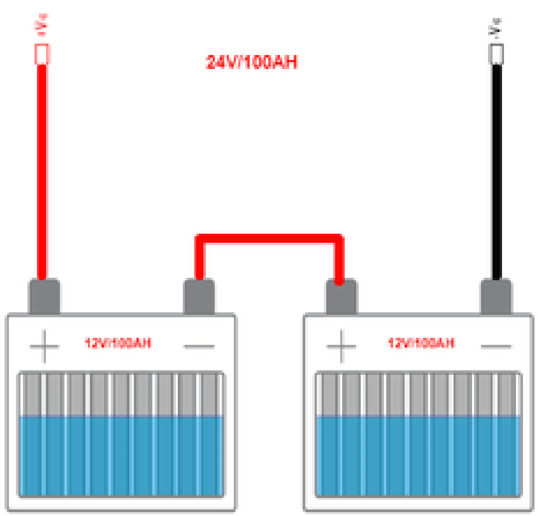
Example: Connecting two 12V /100AH batteries in series will produce 24V, but the total capacity remains the same (100AH).

Parallel Connection:

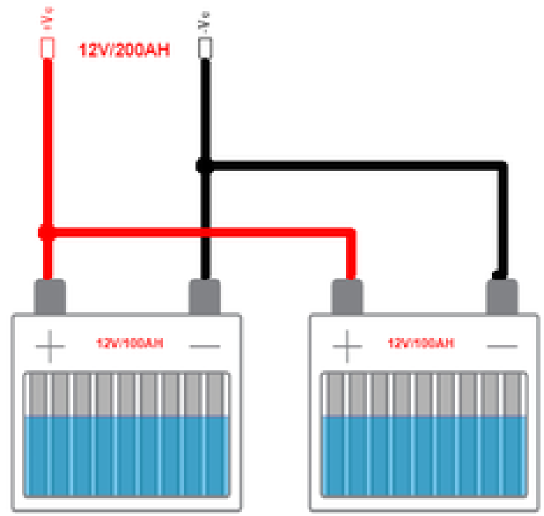
Parallel connections will increase your current rating (Amp-Hours), but the voltage will stay the same. It's important to note that because the amperage of the batteries increased, you may need a heavier-duty cable to keep the cables from burning out.

Example: Connecting two 12V /100AH batteries in parallel will produce 12V, but the total capacity will be increased to 200AH.

Image credit : epsolarpv



Series Connection



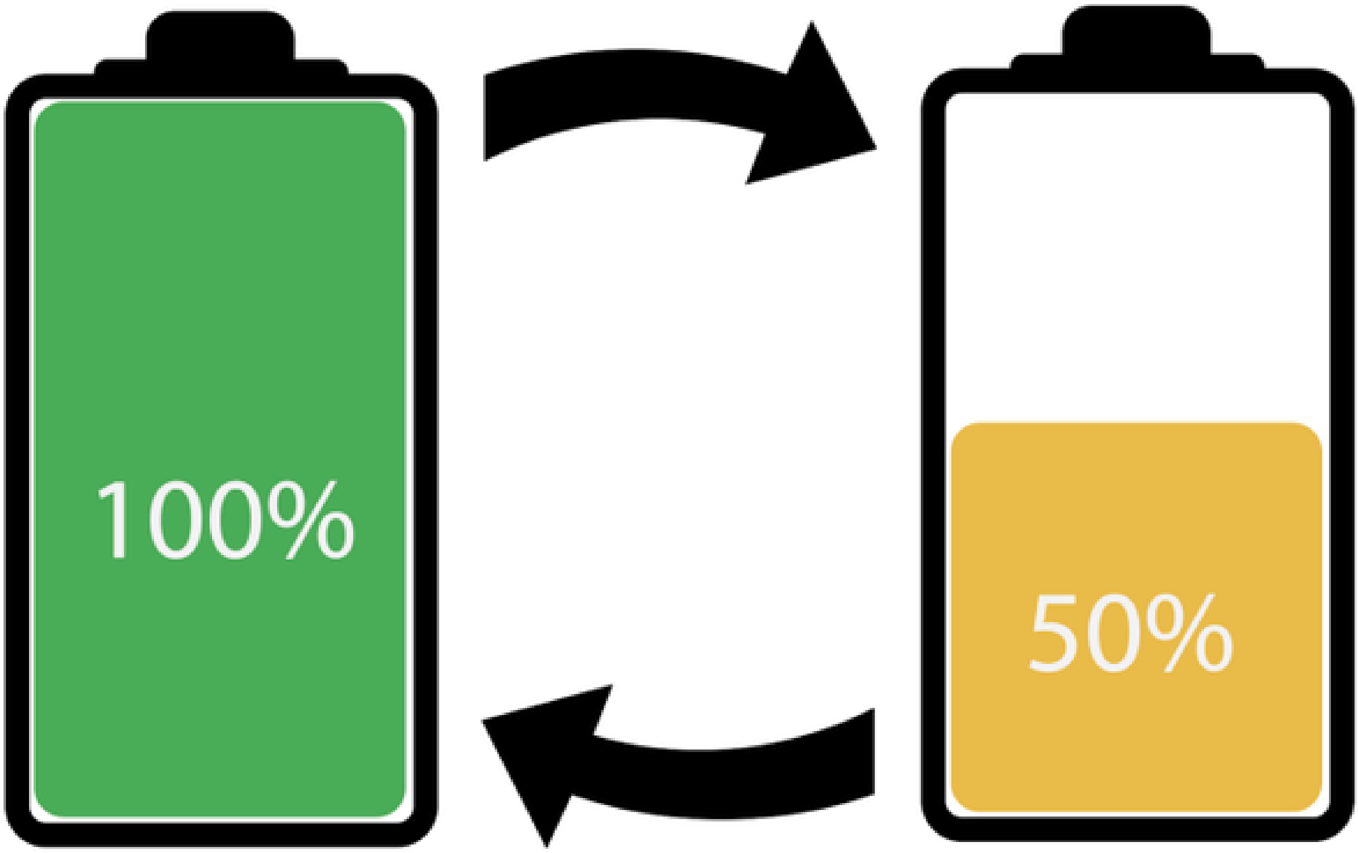
Parallel Connection

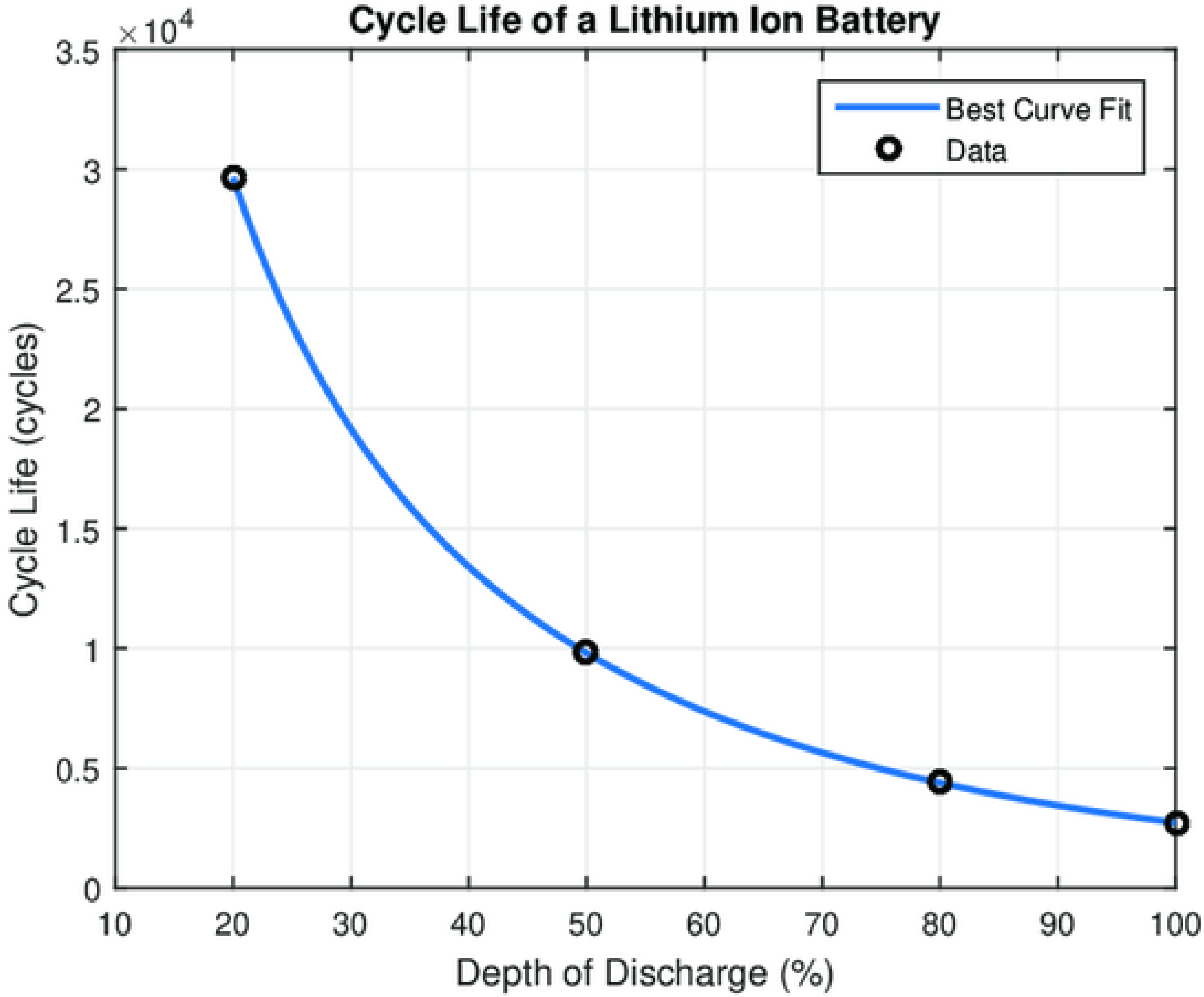
Step 9: Depth of Discharge

The battery's Depth of Discharge (DOD) is the percentage of the battery capacity that can be safely drained without damaging the battery.

As you can see in the above figure, the more a battery is allowed to discharge, the shorter its lifespan. Deep cycle batteries are designed to discharge 80% of their capacity but are recommended to choose a value of around 50% as a good trade-off between longevity, cost.

For a deep cycle battery, 50% and for a lithium battery 80% DOD is considered as good practice.


100%
50%



Step 10: Battery Sizing

Battery Capacity (AH) = Daily Energy Consumption (Watt-Hour) / (System Voltage x DOD)

Example:

Daily energy consumption =719WH (Calculated in the earlier step)

System Voltage = 12V

DOD = 50% for Flooded Lead Acid Battery

Battery Capacity = 719WH / (12V x 0.5) = 119.8AH

You have to select a battery with a capacity of more than 119.8AH. The nearest value available in the market is 120AH.

Battery Selected: 12V / 120AH

I have purchased 150AH by considering future expansion.

Step 11: Select the Solar Panel

Solar Panel converts the sunlight into electricity. A specific amount of sun's energy can be converted to electricity by the solar panel since they are not 100% efficient and they cannot trap the full energy of sunlight. Most of the solar panels are less than 20% efficient, which means that they can just trap about 20% of sunlight energy.

Commonly they are 3 types: Monocrystalline, Polycrystalline, and Thin Film.

1. Monocrystalline:

Monocrystalline solar cells are more efficient because they are cut from a single source of silicon.

As monocrystalline solar cells are made out of a single crystal of silicon, electrons are able to flow easier through the cell, which makes the efficiency higher than other types of solar panels. The efficiency can range from 17% to 22%.

Because of the way that monocrystalline panels are manufactured, they end up costing more than other kinds of solar panels.

2. Polycrystalline:

Polycrystalline solar cells are blended from multiple silicon sources and are slightly less efficient. The multiple silicon crystals in each solar cell make it harder for electrons to flow. This crystal structure makes the efficiency rate of polycrystalline panels lower than monocrystalline panels. Polycrystalline panel efficiency ratings will typically range from 15% to 17%.

Polycrystalline solar panels are cheaper to produce than monocrystalline panels. Most of the residential installations use Polycrystalline solar panels.

3. Thin Film:

Thin-film solar panels are made by depositing a thin layer of a photovoltaic substance onto a solid surface, like glass. Examples of these photovoltaic substances include Amorphous silicon (a-Si), Cadmium telluride (CdTe), Copper indium gallium selenide (CIGS), Dye-sensitized solar cells (DSC).

The main advantage of amorphous solar cells is that they can generate electricity in weak light conditions. However, the main problem of amorphous solar cells is the low photoelectric conversion efficiency, which is about 10-13% only.

Which One You Should Choose?

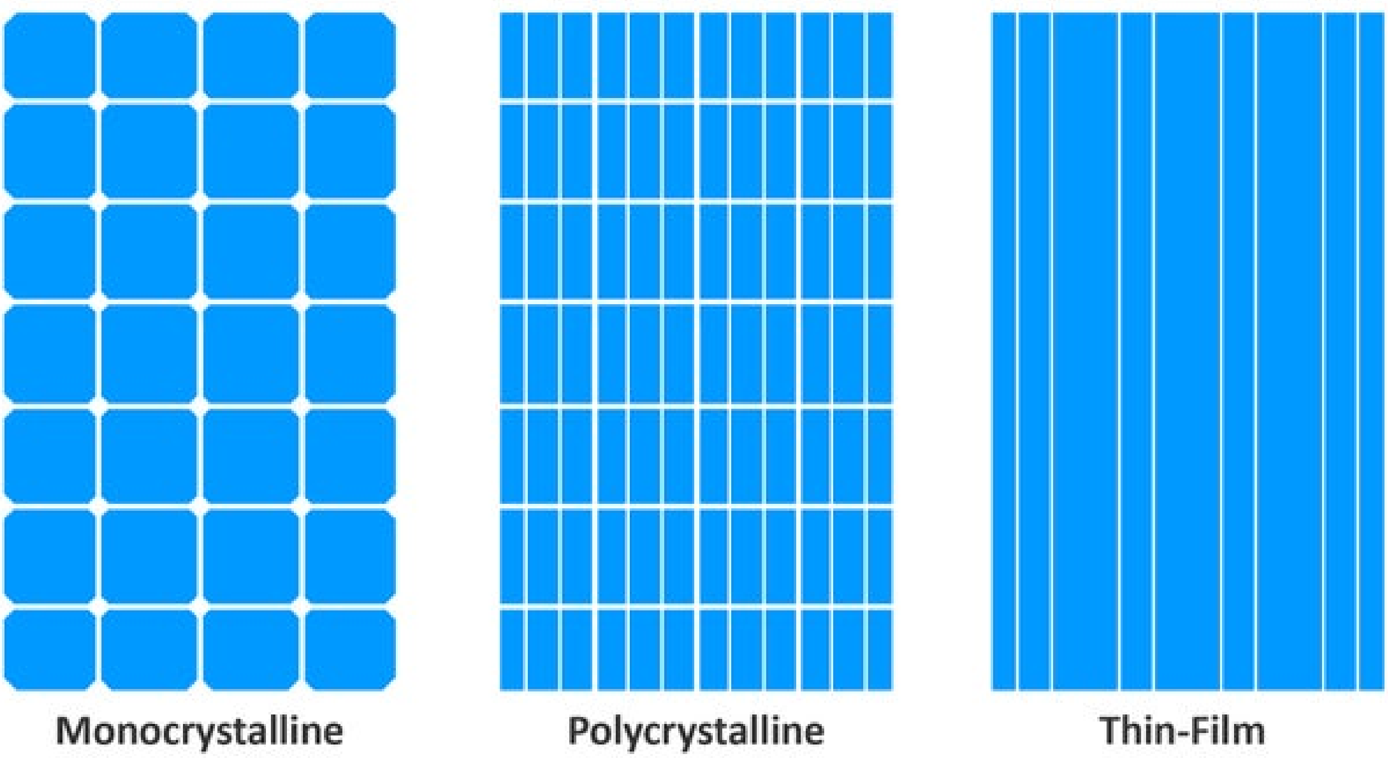
For most residential solar panel installations, it makes the most sense to install monocrystalline panels. Although you have to pay a higher price, you get better efficiency and a sleeker aesthetic than you would with polycrystalline panels.

If you're on a tight budget, however, polycrystalline panels might make more sense for you.

Thin-film solar cells are mostly used in large scale operations, such as utility or industrial solar installations because of their lower efficiency ratings.

I will always recommend purchasing a good brand solar panel. A good brand solar panel company always invests heavily in the quality of its manufacturing process, as well as in its reputation.

Image credit : epsolarpv


Monocrystalline
Polycrystalline
Thin-Film

Step 12: Factors Determine the Solar Panel Sizing

The sizing of the solar panel used in an off-grid system depends on the following factors:

1. Daily energy consumption
2. Number of Peak sun hours
3. Solar panels efficiency

Step 13: Peak Sun Hours

The first step for sizing the solar panel is to determine the amount of sunlight received where you live. While the amount of sunlight your panels receive is important, a more accurate representation of the amount of energy your panels can produce is peak sun-hours.

What is Peak Sun-Hours?

The peak sun hours is the number of hours per day during which the average solar irradiance (sunlight) is 1000 watts per square meter (W/m2) or 1 kilowatt per square meter (kW/m2).

One peak sun hour = 1000 W/m2 or 1kWh/m2 of sunlight

Example: If a given location receives a total of 6,650 Wh/m2 of solar radiation over the course of a day, then that location gets 6.65 peak sun hours. You can see the above picture for a clear understanding.

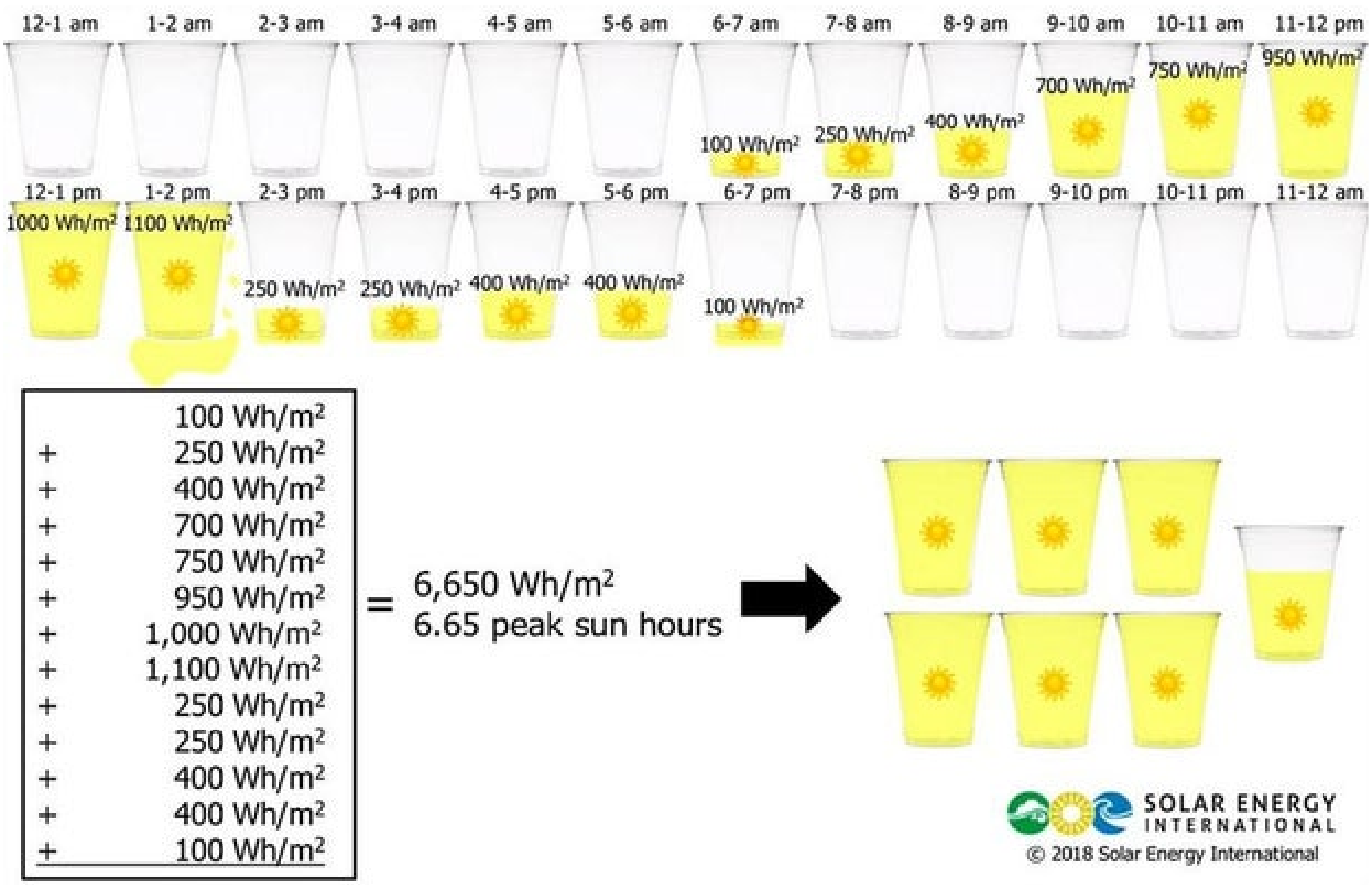
The following factors affect the number of peak sun hours:

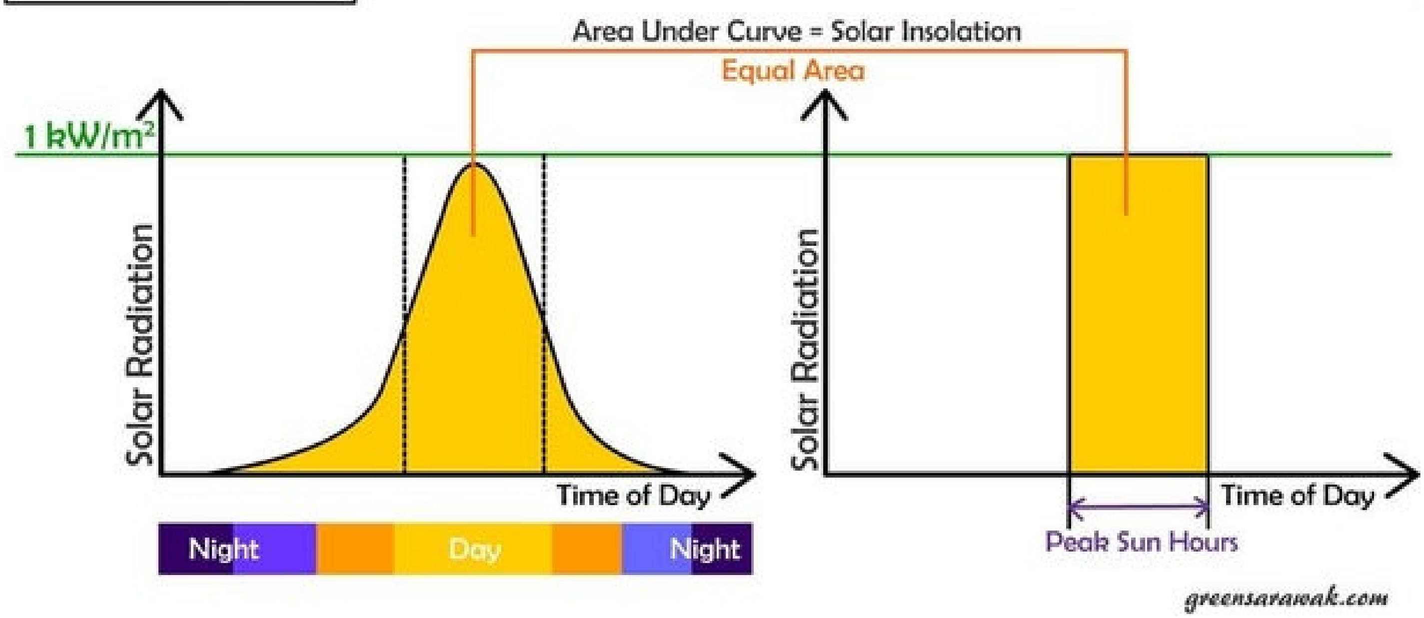
1. Geographical Location: Solar panels installed at a different location, receive different amounts of sunlight. The panel installed near the equator receive maximum sunlight, as it is closer to the sun.

2. Time of Day: The amount of sunlight falling on the solar panel, varies throughout the day, based on the sun's position in the sky. It receives maximum at noon and a minimum during the morning and evening.

3. Season: Maximum amount of sunlight received during the summer and minimum amount during the winter.

Image source: Solar Energy International and Global Solar Atlas





Step 14: How to Calculate Total Peak Sun Hours?

The solar irradiance map can show you the amount of solar energy your location receives on an average day during the worst month of the year.

To find out the amount of solar insolation in your area, you can use the Global Solar Atlas. Follow the following steps:

Step-1: Search your location

Step-2: Choos the PV system configuration (e.g - Small residential)

Step-3: Click on Annual Average (Daily Average in kWh/m2 per day)

Step-4: The number is the peak sun hours

As per the Global Solar Atlas, New Delhi, India receives **5.093 kWh/m2** per day

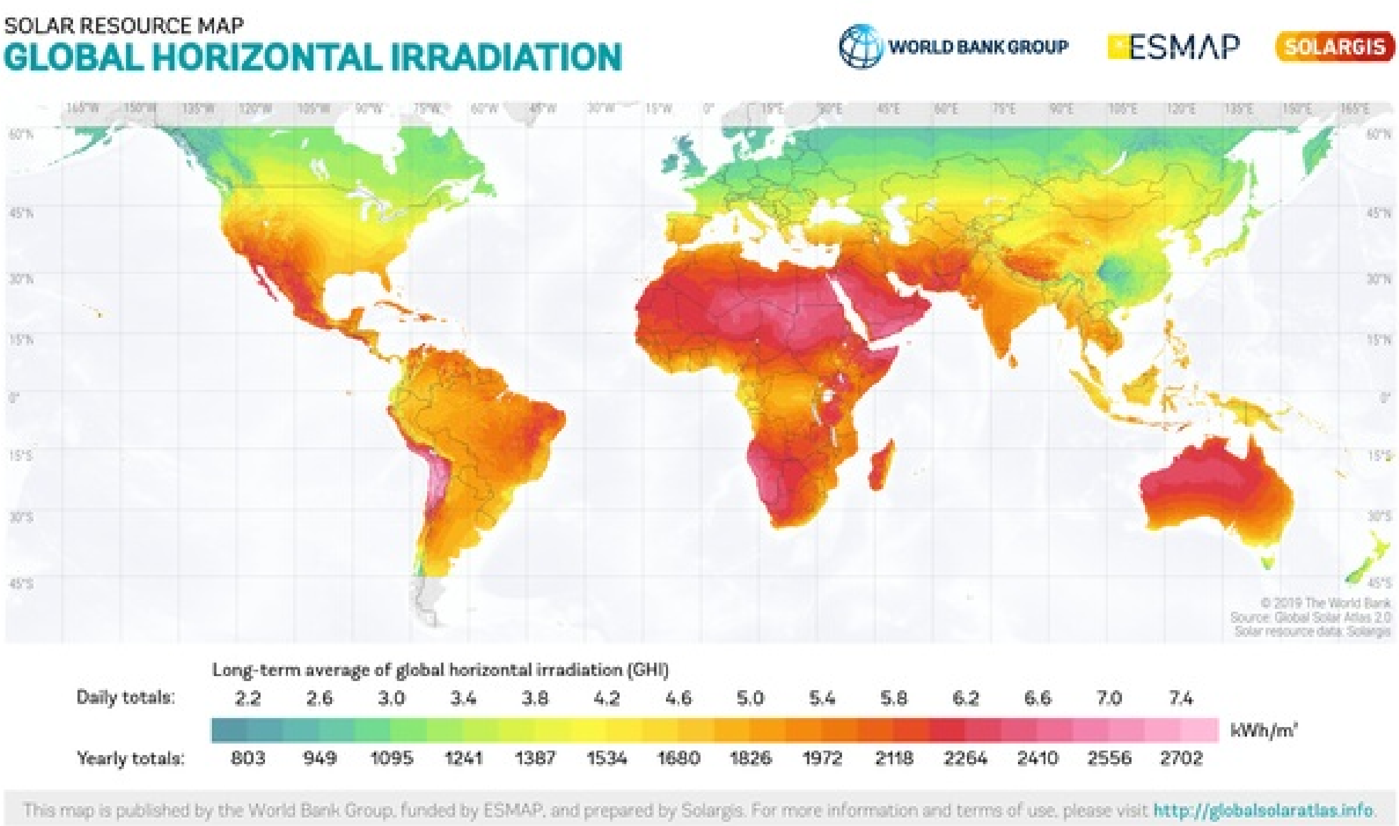
Peak Solar Radiation = 1 kW/m2 (Solar Panels are rated at an input rating of 1kW/m2.)

Peak Sun Hours = 5.093/1 = 5.093 Hours

If we consider the worst scenario, we have to choose a number lesser than that obtained in the above. So here I have chosen **4.5 Hours**.

If you are situated in North America, you can use this reference chart, to get the number of peak sun hours.

Reference for Solar Insolation Map: NREL



Step 15: System Efficiency

You will never get the rated power from the solar system because there are few losses associated with it like :

1. Soiling Loss: Loss due to dust deposition on the solar panel

2. Shading Loss: Loss due to shadow by trees and building near to the panels

3.Wiring Loss: Loss arises in the inter panels cabling and cable from panels to the battery bank.

The typical efficiency is **70%** (considered the worst situation)

Clean

Dusty

Step 16: Solar Panel Sizing

You can use the below formula to determine the solar panel wattage:

Solar Panel Watt = Daily energy consumption (WH) / (Peak Sun Hour x system efficiency)

Daily energy consumption = 719WH

Peak Sun Hour = 4.5Hrs

Panel Watt = 719 / (4.5 x 0.7) = 228.25W

We have to buy a solar panel with a rating more than the above-calculated value. The nearest value of the panel available in the local market was 250W or 260W.

I have purchased a 260W because the price between the two panels was not much different.

Final Rating: 250W / 12V

How Many Solar Panels Required?

If the power calculated in the above higher than a single panel, you have to purchase more panels, in that case:

Number of solar panels=Required solar panels (Watts) / Selected panels Watt

Example:

Required panel watt = 1320W

Solar panel selected = 330W

Number of panels = 1320 /330 = 4

You have to purchase 4 numbers of 330watt panels.

Step 17: How to Wire Solar Panels?

You can connect the solar panels in the following 3 ways:

1. Series: Current remains the same while the voltage of the panels will be added to each other.

2. Parallel: Voltage remains the same while the number of currents will be added.

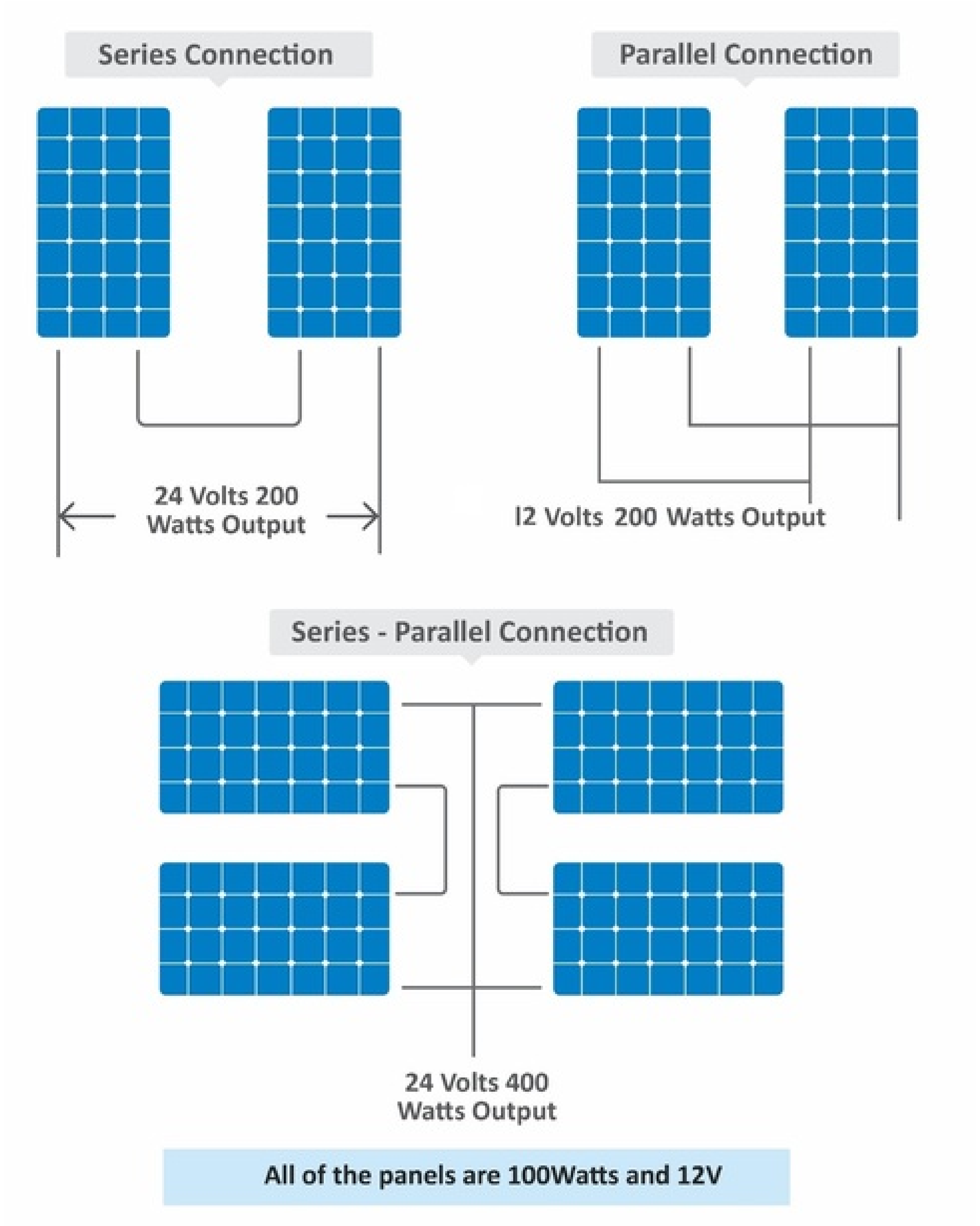
3. Series-Parallel: Strings of series panels connected in parallel

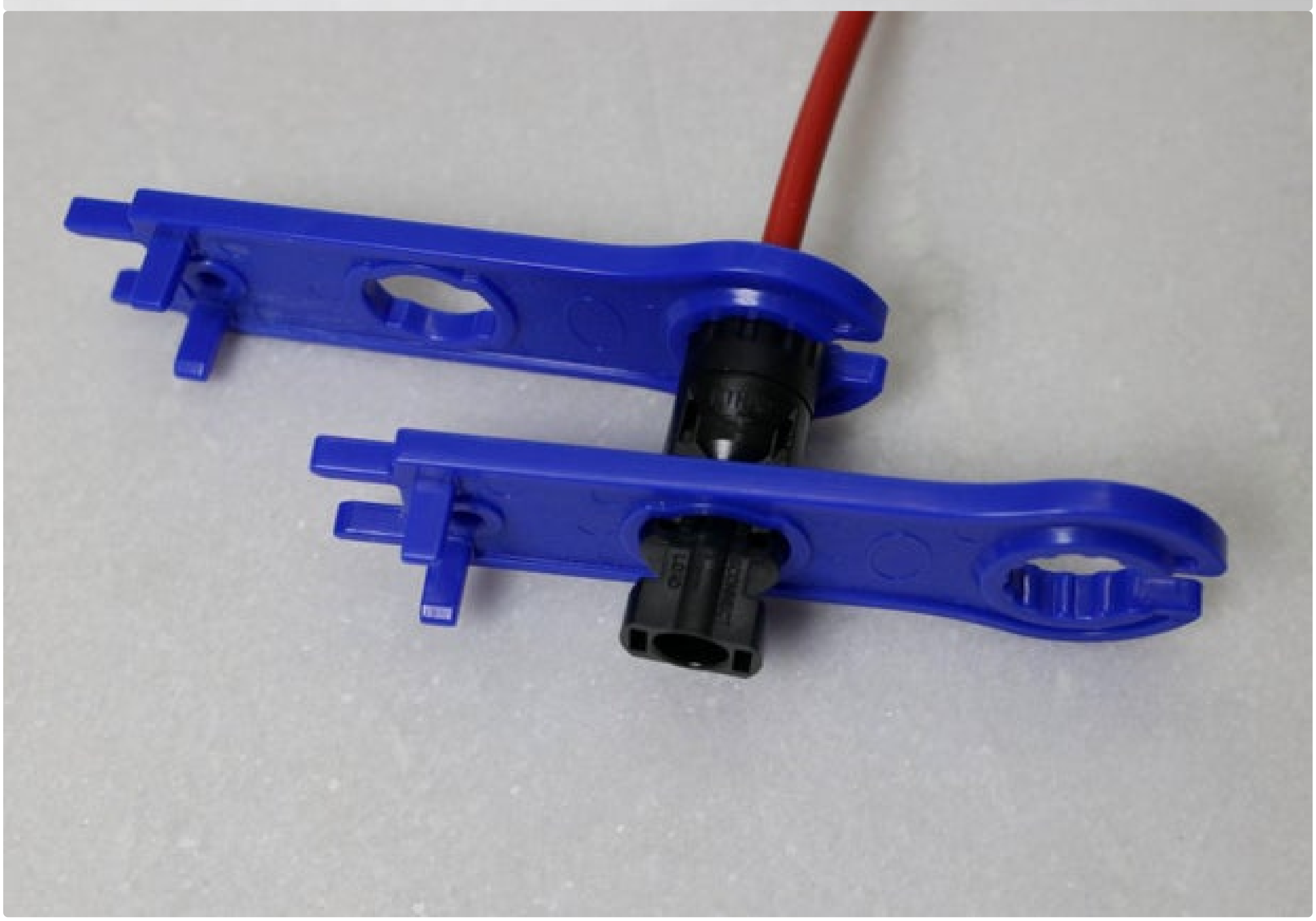
When deciding between the above three configurations, two important facts to consider are the maximum input voltage of your charge controller and the type of charge controller (PWM or MPPT).

To connect the solar panels in the above 3 configurations, you need MC4 Connectors and spanners to connect and disconnect them. I have already written separate Instructactables on this.

Note: *Every charge controller has limits on how much voltage it can accept (maximum input voltage). You must ensure that the power coming in from your solar panels never exceeds this number.*

Image credit : epsolarpv


Series Connection
Parallel Connection
24 Volts 200
Watts Output
12 Volts 200 Watts Output
Series - Parallel Connection
24 Volts 400
Watts Output
All of the panels are 100Watts and 12V



Step 18: Charge Controller Selection

It is a device that is placed between the Solar Panel and the Battery Bank to control the amount of electric energy produced by Solar panels going into the batteries. The main function is to make sure that the battery is properly charged and protected from overcharging.

As the input voltage from the solar panel rises, the charge controller regulates the charge to the batteries preventing any overcharging and disconnect the load when the battery is discharged.

Types of solar charge controllers
There are currently two types of charge controllers commonly used in PV power systems :

1. Pulse Width Modulation (PWM) Controller

2. Maximum Power Point Tracking (MPPT) Controller


Solar Charge Controller
CMG
DC 12V
SOLAR CHARGE CONTROLLER
EPEVER
TRIRON4215N
MPPT
SOLAR CHARGE CONTROLLER
Relay
Temp Sensor


5V Max. 2.4A
USB
MENU
SET
EPEVER
VS1024AU
Temp.
Sensor

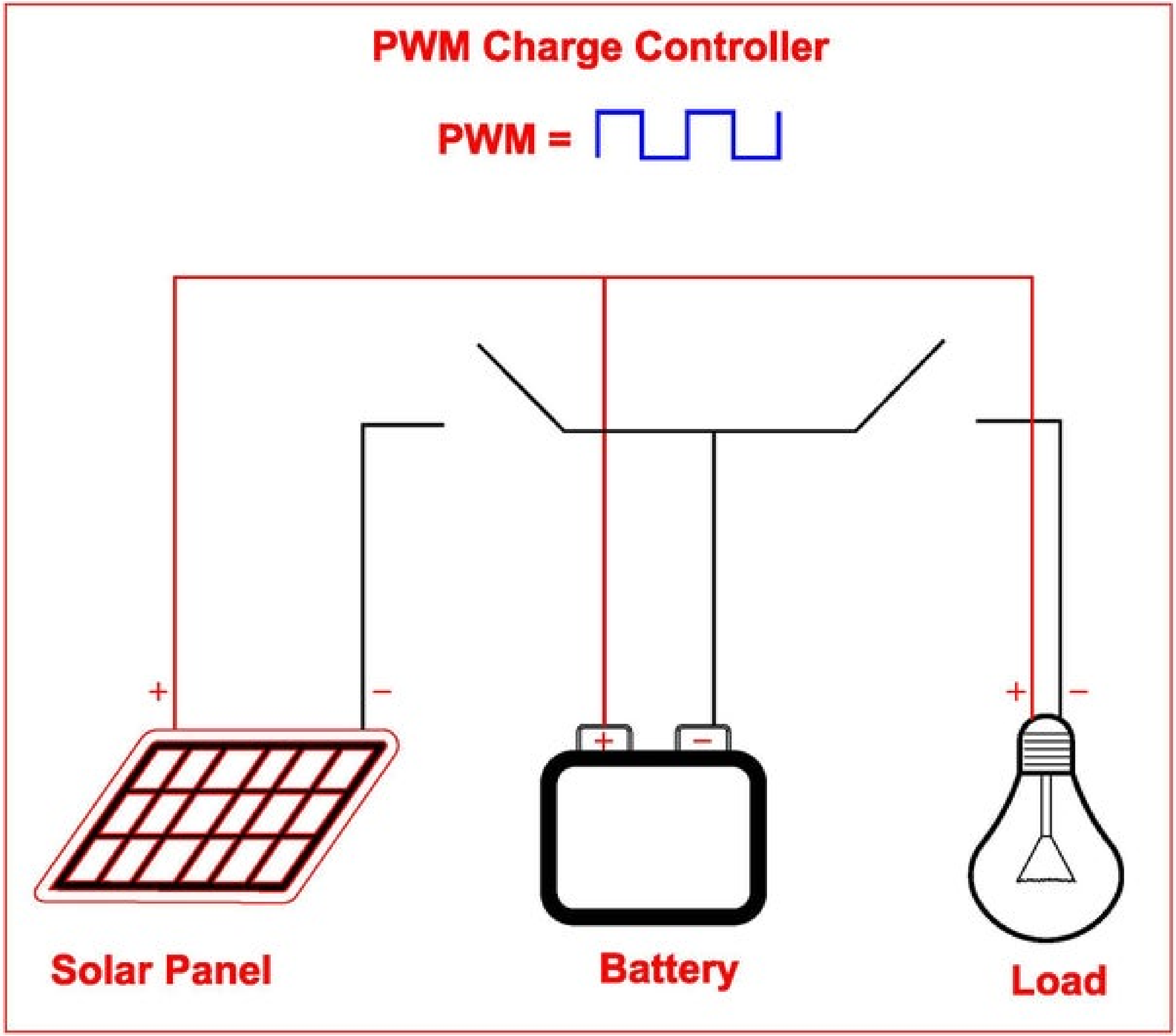
Step 19: PWM Solar Charge Controller

PWM stands for Pulse Width Modulation, which stands for the method it uses to regulate charge. Its function is to pull down the voltage of the solar array to near that of the battery to ensure that the battery is properly charged. In other words, they lock the solar panel voltage to the battery voltage by dragging the Solar panel Vmp down to the batteries system voltage with no change in the current.

It uses an electronics switch (MOSFET) to connect and disconnect the solar panel with the battery. By switching the MOSFET at a high frequency with various pulse widths, a constant voltage can be maintained. The PWM controller self-adjusts by varying the widths (lengths) and frequency of the pulses sent to the battery.

When the width is at 100%, the MOSFET is at full ON, allowing the solar panel to bulk charge the battery. When the width is at 0% the transistor is OFF open circuiting the Solar panel preventing any current from flowing to the battery when the battery is fully charged.


USB
MENU
SET
EPEVER
VS1024AU
Temp Sensor


PWM Charge Controller
PWM =
+
−
+
−
+
−
Solar Panel
Battery
Load

Step 20: MPPT Solar Charge Controller

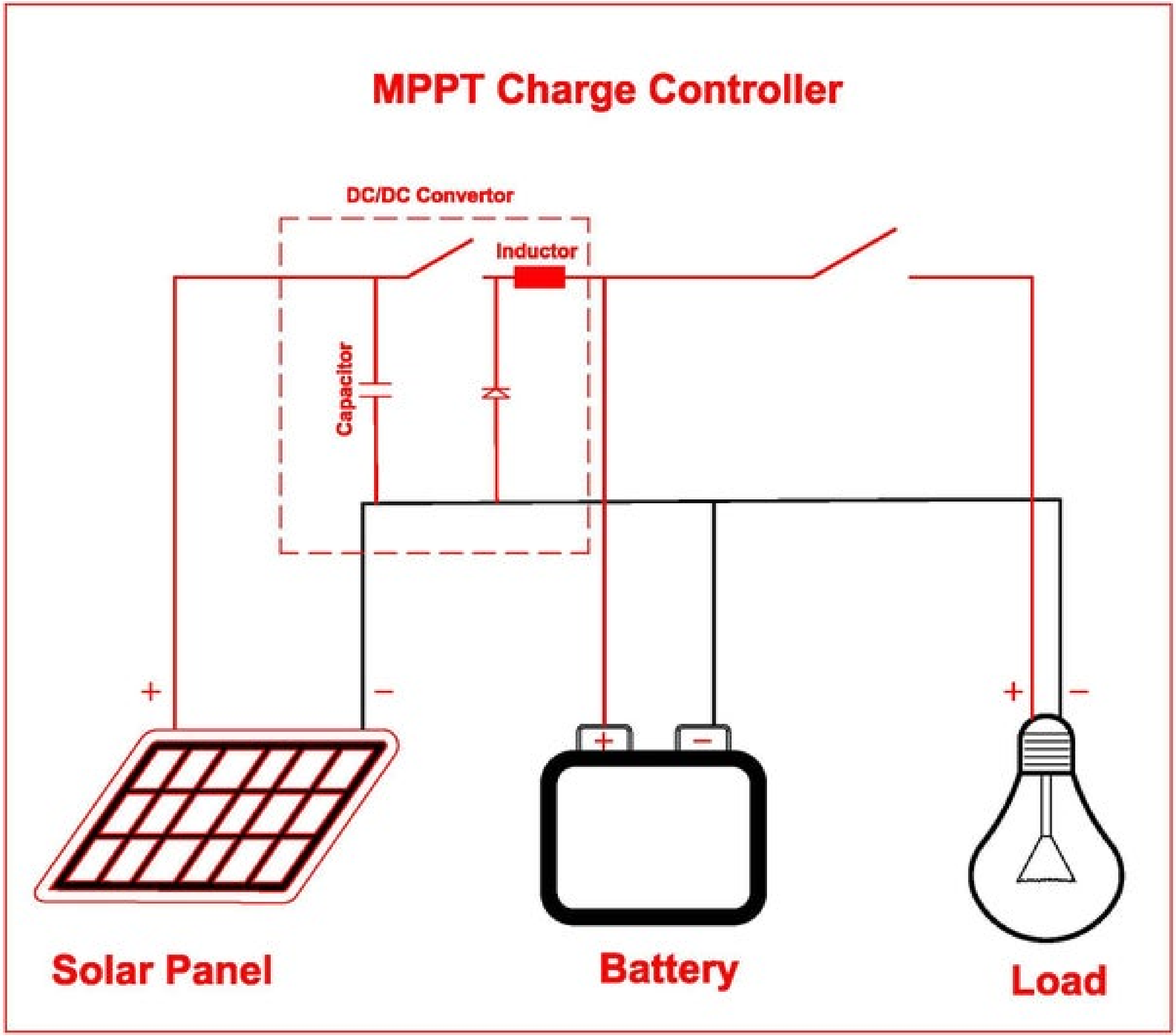
MPPT charge controller extracts the maximum power from the PV module by forcing the PV module to operate at a voltage close to the Maximum Power Point (MPP). It has been designed to adjust its input voltage to utilize the maximum power output of the solar array and then transform this power to supply the varying voltage requirement. The input voltage is varied by using a DC/DC converter.

MPPT controllers do this via an adaptive algorithm that follows the maximum power point of the Solar panel/array and then adjusts the incoming voltage to maintain the most efficient amount of power for the system.

The performance advantage of an MPPT controller is substantial (10% to 40%) when the solar cell temperature is low (below 45°C). They are more efficient than the PWM controller. The efficiency of a typical MPPT controller is around 94-99%.

To fully exploit the potential of the MPPT controller, the array voltage should be substantially higher than the battery voltage. The MPPT controller is the best solution for higher power systems.


EPEVER
TRIRON4215N
PV / +
BATT / →
LOAD / −
SET
ESC
MPPT
SOLAR CHARGE CONTROLLER
Relay
RS485
SLAVE
Temp
Sensor


MPPT Charge Controller
DC/DC Convertor
Inductor
Capacitor
+
−
+
−
+
−
Solar Panel
Battery
Load

Step 21: Sizing of Charge Controller :

Choosing the most suitable charge controller requires two steps:

1 . Voltage Selection: The charge controller voltage shall be matched with the system voltage. The standard configurations are 12, 24, and 48 volts. If you are wiring your batteries for 12 volts you need a charge controller that is rated at 12 volts.

Some controllers are voltage specific, meaning that the voltage cannot be changed or substituted. Other more sophisticated controllers include a voltage auto-detect feature, which allows it to be used with different voltage settings.

2. Current Selection: To select the proper Charge Controller, you have to know the maximum output current of the solar panel and Battery Voltage.

The maximum possible current in the system = (Solar panel Wattage / System voltage) × Safety factor

Safety Factor :

We use a standard factor to account for all Solar panel output-boosting circumstances like a sunny day with a very clear snowpack. (additional light reflected off the snow). That factor is 1.3 or 130%

PV Charge Controller - Upper Voltage Limit

Charge controllers have an upper voltage limit. This refers to the maximum amount of voltage they can handle from the solar array. Make sure you know what the upper voltage limit is and that you don't exceed it or you may end up burning out your solar charge controller.

Sample Calculation

Example

Consider a 260W solar panel is used to charge a 12V battery bank.

1. Voltage Rating:

The voltage rating of the charge is controller shall be equal to the system voltage i.e 12V in this case.

2. Current Rating:

Rating = (Solar panel Wattage / System voltage) × Safety factor (1.3)

Rating = (260W / 12V) x 1.3 = 28.16A

So, the solar charge controller rating is selected as **30 Amps /12 Volt**

Step 22: PWM or MPPT ?

With a PWM controller, the current is drawn out of the panel at just above the battery voltage, whereas with an MPPT controller the current is drawn out of the panel at the panel maximum power voltage (Vmp). To understand this concept, let's take an example.

Example: Consider a 100 Watt panel with a current(Imp) of 5.75A & voltage (Vmp) of 17.40V connected to a 12 V lead-acid battery.

PWM Controller

With a PWM controller, the panel voltage would be dragged down near to the voltage of the battery but the current stays the same at 5.75 amps. This happens because Solar Panels behave like a current source, so the current is determined by the available sunlight.

Now the power (P)= Vbat x Imp = 12V x 5.75A = 66.6W. So the Solar panel is now behaving like a 66-watt panel.

MPPT Controller

With an MPPT controller, the panel voltage will operate at voltage close to the Maximum Power Point (MPP), and the current stays the same at 5.75 amps.

Now the Power = Vmp x Imp = 17.4 x 5.75 =100W

This equates to a loss of 100W-66.6W = 33.4W

However the above calculation is overly-optimistic as the voltage drops as temperature increases; so assuming the panel temperature rises to say 30°C above the standard test conditions (STC) temperature of 25°C and the voltage drops by 4% for every 10°C, i.e. a total of 12%.

Then the power drawn by the MPPT will be 5.75A * 15.3V = 88W

Power loss = 88-66.6 =21.4W, i.e. 21% more power than the PWM controller.

Which One Should I Purchase?

When you are finding which type of solar charge controller to purchase, you need to know about their functionality and features.

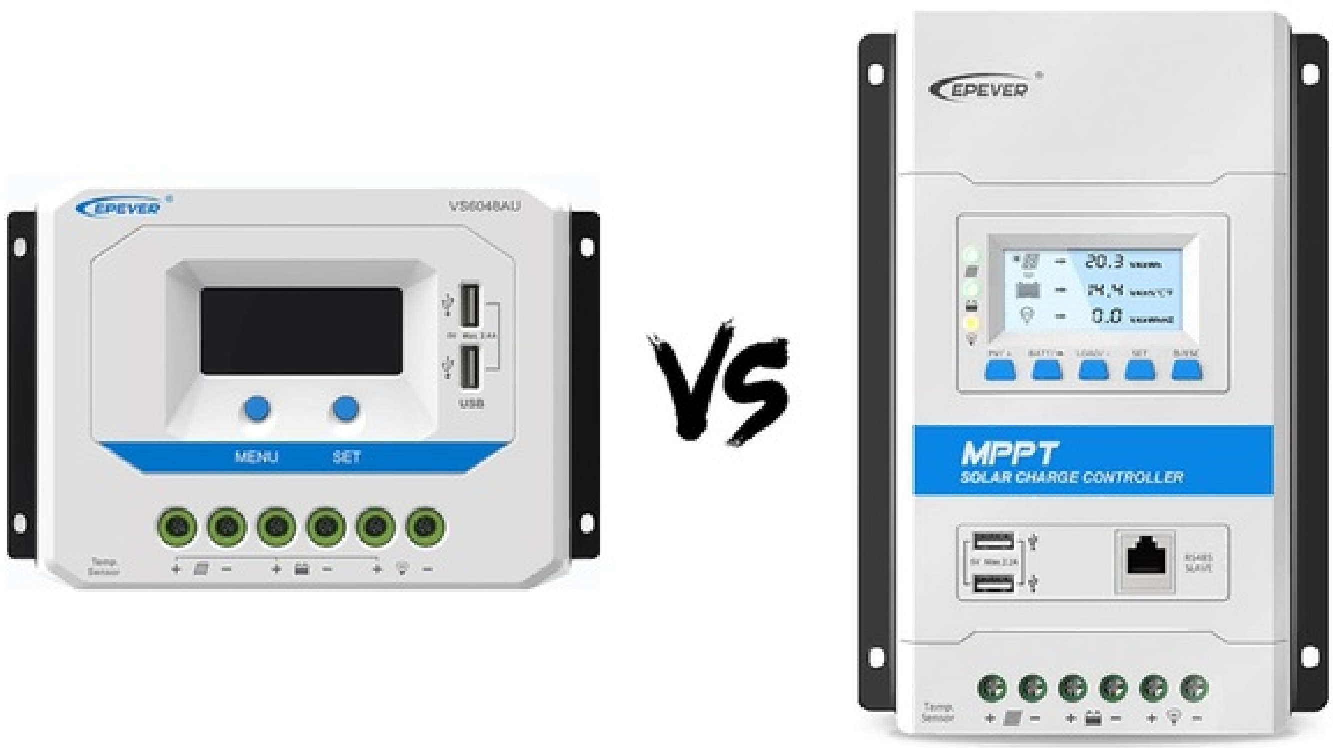
1. PWM controller is best for small off-grid power applications that don't need any other features and has no much budget. If you just want the basic and economical charge controller then the PWM controller is the best option for you.

2. MPPT controller is best for a larger system (Off-grid power station, RV Solar Power, Boat, Hybrid Solar Power, etc.) . When the solar array voltage is substantially higher than the battery voltage, then MPPT is the best controller. e.g. Connecting a 72cell solar panel, for charging a 12V battery.

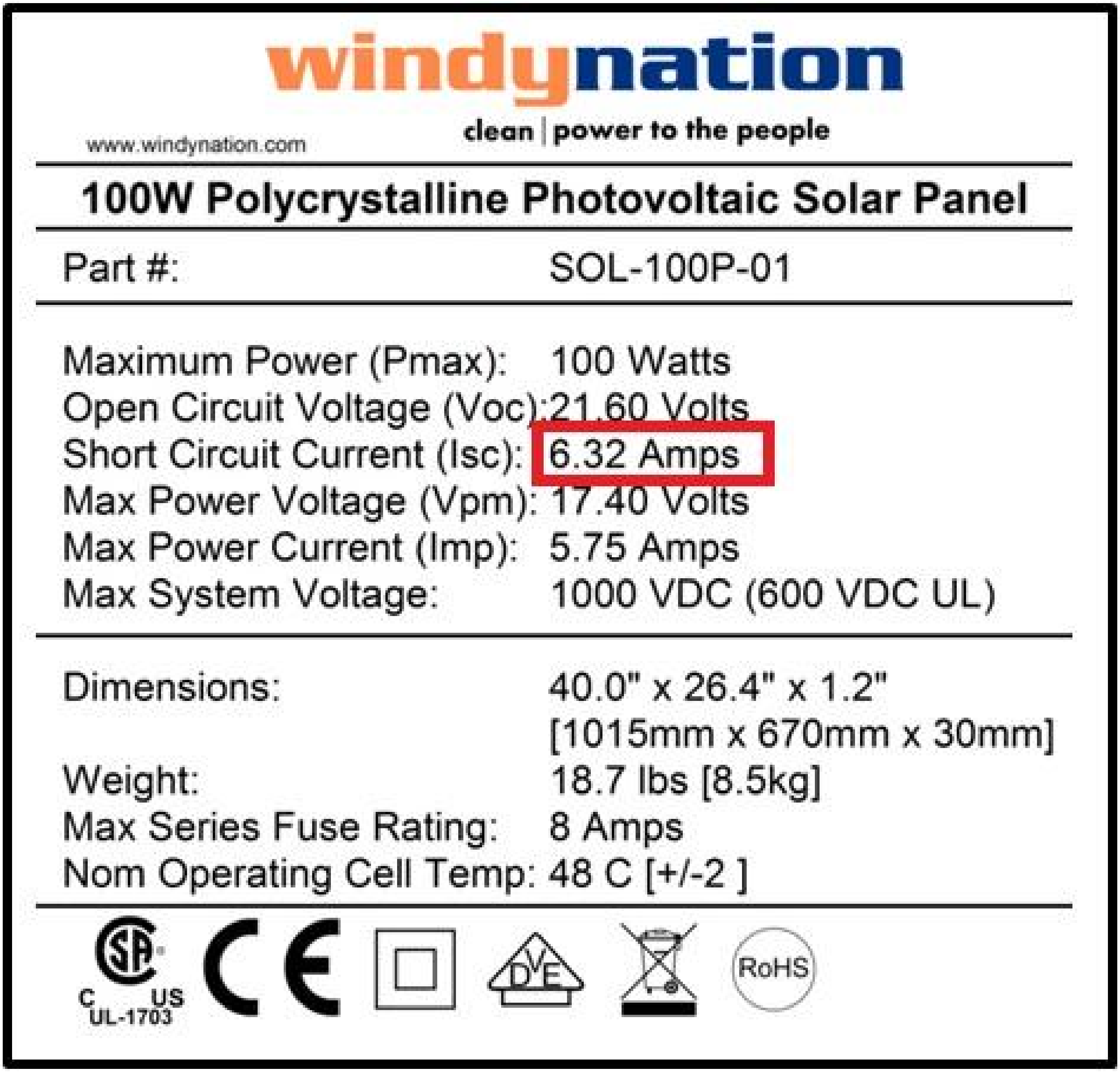
You can look at the above comparison table for PWM and MPPT Solar Charge Controllers.

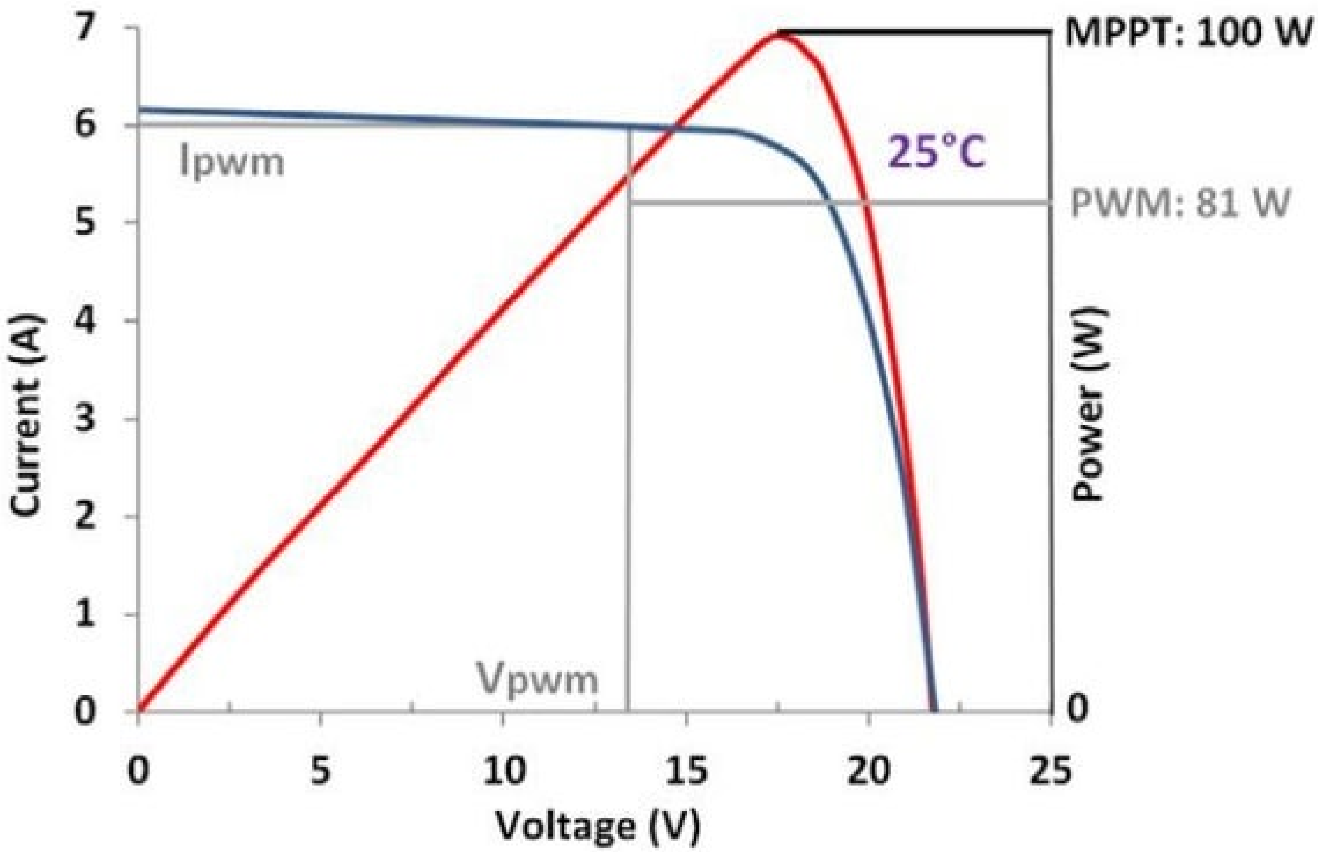
You can read a nice document on selecting the PWM or MPPT charge controller prepared by victronenergy.

Image credit : epsolarpv



PWM	MPPT
PROS	
These controllers are inexpensive. The cost is 1/3 – 1/2 of a MPPT controller.	More expensive than a PWM controller. The cost is 2-3 times of PWM.
PWM controllers are available in sizes up to 60 Amps	You can get sizes up to 80 Amps.
Efficiency is low.	Up to 30% higher charging efficiency. (especially in cool climates)
CONS	
The Solar input nominal voltage must match the battery bank nominal voltage. Cannot be used efficiently with 60-cell panels.	MPPT controllers are more expensive.
PWM controllers have limited capacity for system growth.	MPPT units are generally larger in physical size.


windynation
www.windynation.com
clean | power to the people
100W Polycrystalline Photovoltaic Solar Panel
Part #: SOL-100P-01
Maximum Power (Pmax): 100 Watts
Open Circuit Voltage (Voc): 21.60 Volts
Short Circuit Current (Isc): 6.32 Amps
Max Power Voltage (Vpm): 17.40 Volts
Max Power Current (Imp): 5.75 Amps
Max System Voltage: 1000 VDC (600 VDC UL)
Dimensions: 40.0" x 26.4" x 1.2"
[1015mm x 670mm x 30mm]
Weight: 18.7 lbs [8.5kg]
Max Series Fuse Rating: 8 Amps
Nom Operating Cell Temp: 48 C [+/-2]
C US
UL-1703
RoHS



Step 23: Inverter Selection

Solar inverters are one of the most important components of a solar panel system. They're responsible for converting direct current (DC) electricity from your solar panels to alternating current (AC) electricity to power your appliances.

If you are only running DC loads straight off your battery bank, you can skip this step. But, if you are powering any AC loads, you need to convert the direct current from the batteries into alternating current for your appliances.

Common Types Of Inverter:

1. Square Wave

2. Modified Sine Wave

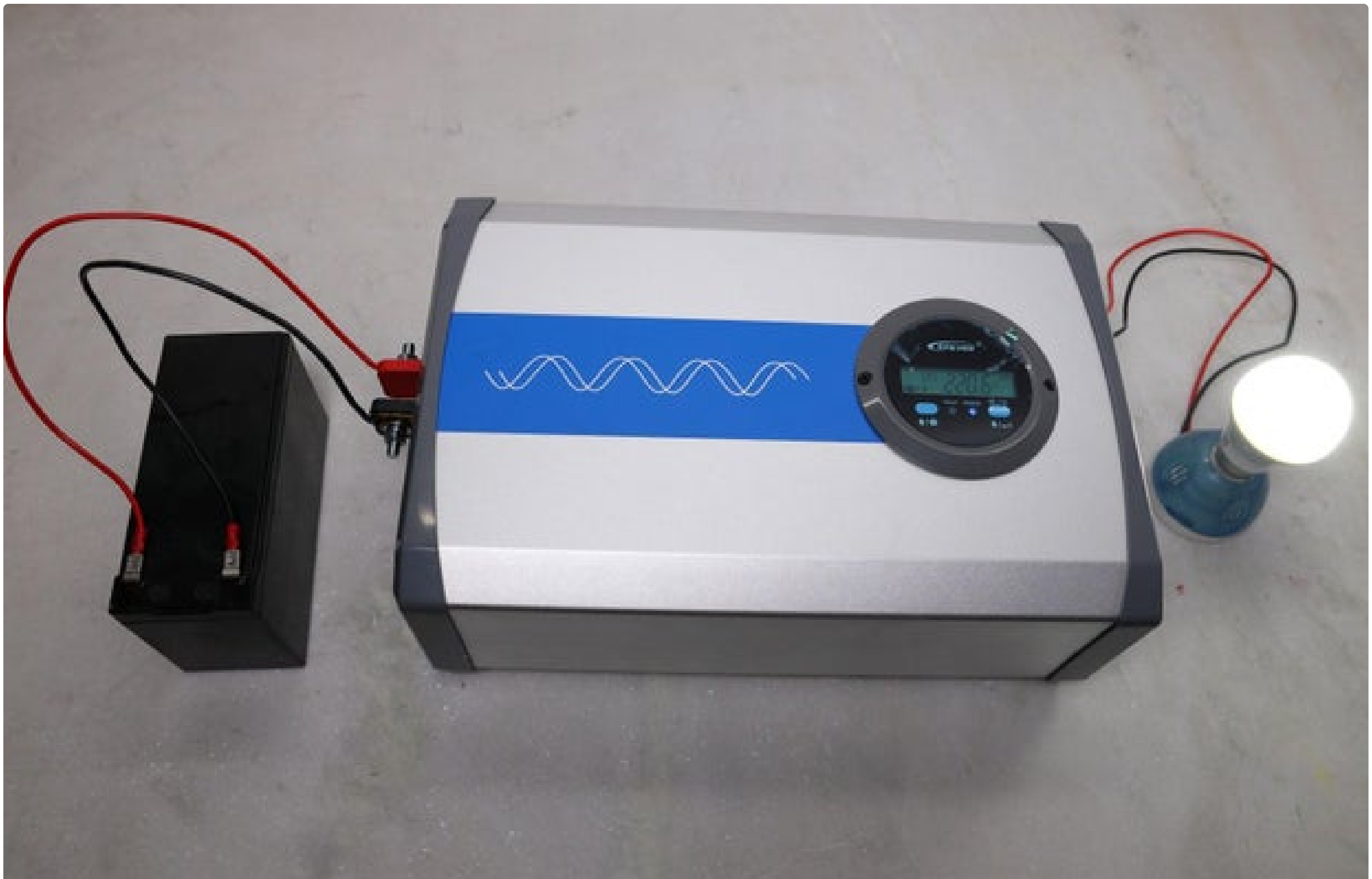
3. Pure Sine Wave

Square wave inverter is cheaper among the all but not suitable for all appliances. Modified Sine Wave output is also not suitable for certain appliances, such as a fridge, microwave oven, sensitive electronic equipment, Laser printers, and most kinds of motors.

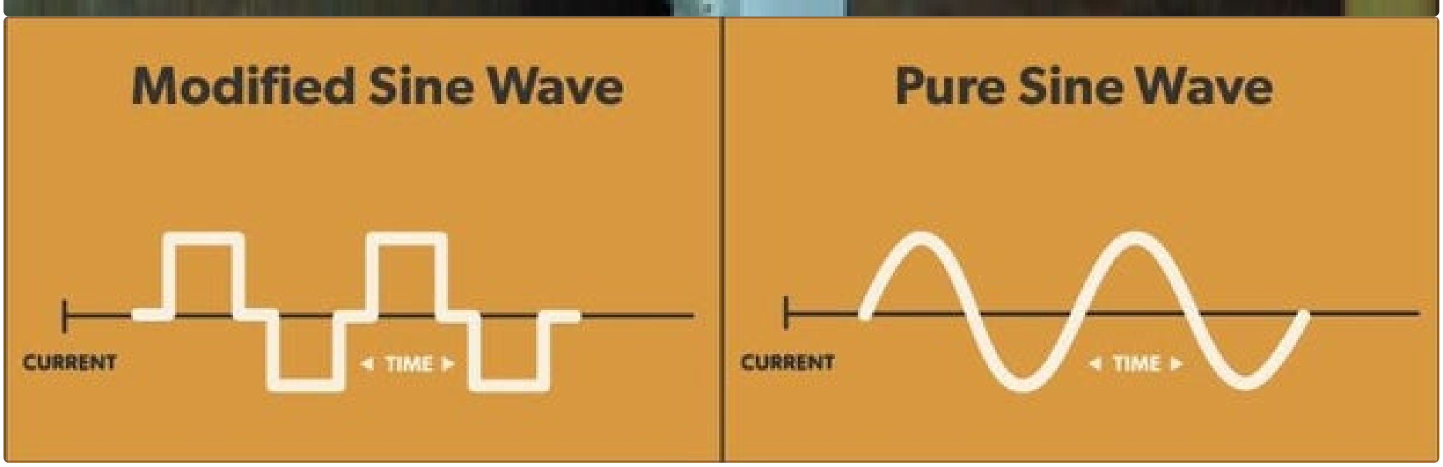
Typically modified sine wave inverters work at lower efficiency than pure sine wave inverters.

So as per my opinion choose a ***pure sine wave inverter***.

Image source: unboundsolar




PRITAM


Modified Sine Wave
CURRENT
TIME
Pure Sine Wave
CURRENT
TIME

Step 24: How Inverter Are Rated?

The inverter is rated for Continuous Watts and Surge watts

1. Continuous Watts :

Continuous watts is the total amount of watts the inverter can support indefinitely. A 2000 watt inverter can power up to 2000 watts continuously. It is also called the nominal AC output power of the inverter.

If you want to run multiple appliances at the same time, just add up the power rating of the equipment that is running together at the same time.

Example: Running a Fan (80W /200W), 2 nos of LED Light (6W), Laptop (65W), and WiFi Router (6W) at the same timeTotal Continuous Watts = 80+12+65+6= **163W**

2. Surge Watts (Peak Watts):

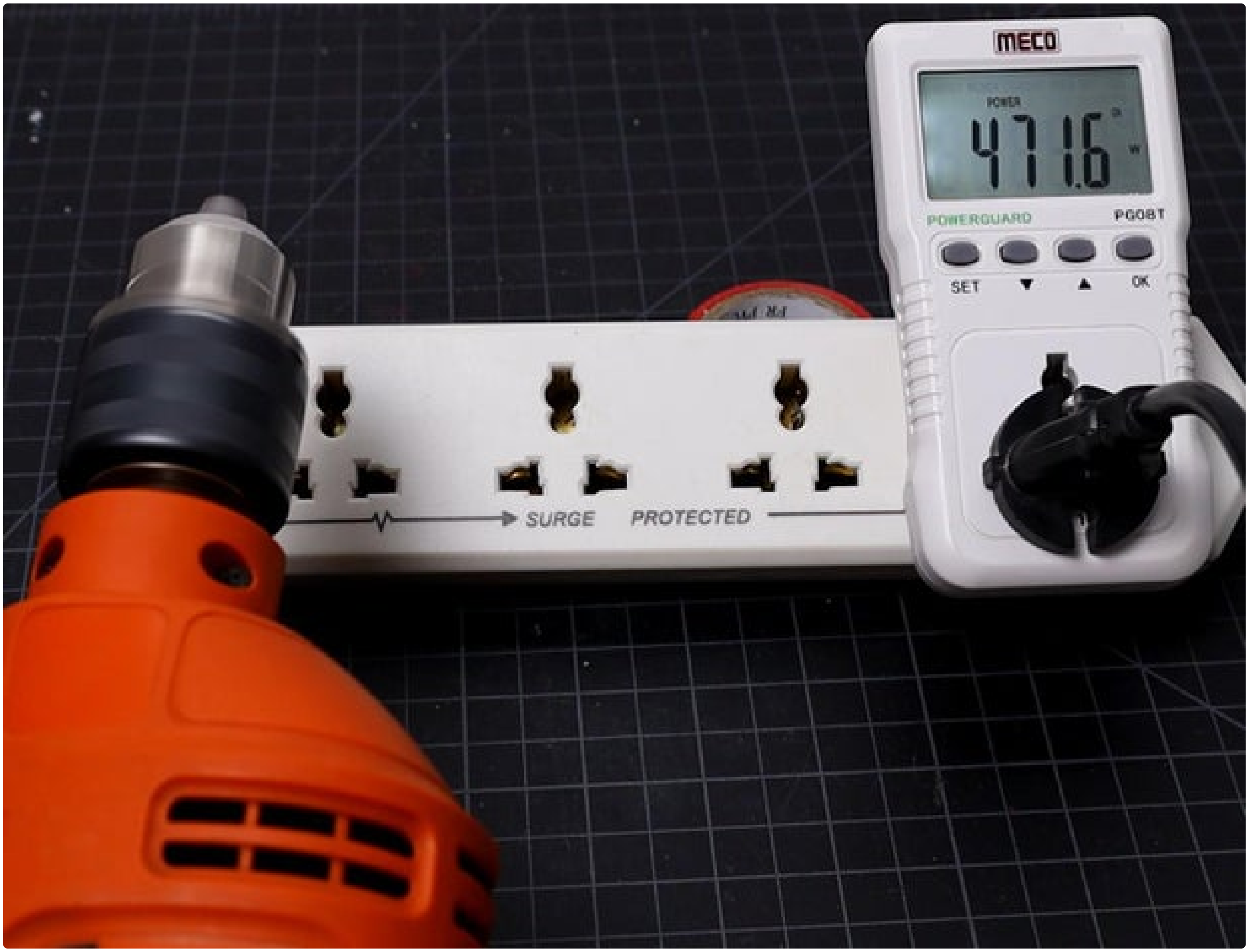
Surge watts is the amount of power the inverter can support for a very short time, usually momentary. A 2000 watt inverter rated at 4000 surge watts can handle up to 4000 watts momentarily while starting things like motors.

In the above picture, you can see the drill draws 471.6W for a short time period.

In our case, the surge power is applicable for the ceiling fan during the starting which is approximately 200W.

Total surge watt = 200+12+65+6 = **283W**

Select the inverter that should support both of these values.


MECO
POWER
471.6
W
POWERGUARD
PG08T
SET
OK
SURGE PROTECTED


MECO
374.3
POWERGUARD
PG08T
SET
OK
SURGE PROTECTED
BLACK&
DECKER

Step 25: Inverter Voltage & Frequency

The next rating you have to look at when sizing an inverter is the input /output voltage and output frequency.

Input Voltage / System Voltage:

For correct solar system sizing, your solar panels, inverter, and battery bank all need to use the same voltage. i.e system voltage.

In the earlier steps, we have selected 12V battery and solar panel, so the input voltage of the inverter must be 12V.

Output voltage:

The common output voltage of an AC outlet is 120/240VAC, based on the location.

Output Frequency:

The two common Inverter output frequencies are 50/60Hz, based on the location.

Before buying the inverter check your country's voltages/frequencies used for domestic appliances.

Step 26: Inverter Efficiency

The efficiency of an inverter indicates how much DC power is converted to AC power. Some of the power can be lost as heat, and also some stand-by power is consumed for keeping the inverter in powered mode.

The general efficiency formula is $\eta inv= Pac / Pdc$

Here Pac is AC power output in watts and Pdc is DC power input in watts.

Step 27: Inverter Sizing

Total Continuous Watts =168W

Total Surge Watts =238

Inverter efficiency = 95%

Continuous Watts Required = 168/0.95 = 176.8

Surge Watts required = 238/0.95 =250.5W

Input Voltage = 12V

For India, the AC voltage and frequency is 230V and 50Hz.

Fina Inverter Rating :

Continuous watts = **200W**

Surge Watts = **400W**

Input Voltage = **12V**

AC Output: **230V/50Hz**

Step 28: Selecting the Solar Cable

The current generated from the solar panels should reach the Battery with minimum loss. Each cable has its own ohmic resistance. The voltage drop due to this resistance is according to Ohm's law

V = I x R (Here V is the voltage drop across the cable, R is the resistance and I is the current).

The resistance (R) of the cable depends on three parameters:

1.Cable Length: Longer the cable, the more is the resistance

2. Cable Cross-section Area: Larger the area, the smaller is the resistance

3. The material used: Copper or Aluminum. Copper has lesser resistance compared to Aluminium In this application, copper cable is preferable.

You can calculate the cable size by using RENOGY online calculator.

You need to enter the following parameters :

1. Solar Panel Operating Voltage (Vmp)

2. Solar Panel Operating Current (Imp)

3. Cable Length from Solar Panel to Battery

4. The expected loss in percentage

The first two parameters (Vmp and Imp) can be easily found from the specification sheet on the backside of the solar panel or from the datasheet. The cable length depends on your installation. The loss percentage considered for good design is around 2 to 3%.

In the earlier step, we have already finalized the Solar panel, the rating. From the Solar panel specification sheet Vmp = 36.7V and Imp = 6.94A (rounded off to next higher number i.e 37V and 7A). Let the distance between the Solar panel and the Battery is 30 feet and the expected loss is 2%. By using the above values in the online calculator by RENOGY, The cable size is 12 AWG.

The calculation screenshot is also attached for reference.

You can buy the Solar cables from Amazon or Aliexpress

You can read my Instructables on How to Make the MC4 Connector .

Note: The voltage grade of the cable should be matched with the Solar Panel maximum system voltage.

Step 29: Selecting the Correct Size Power Inverter Battery Cables

It is very important to be sure you are using the appropriate cable size for your inverter/battery. Failing to do so could lead to your inverter not supporting full loads and overheating, which is a potential fire hazard. Use this as a guide for choosing the proper cable size, and be sure to contact a professional electrician or our tech team with any additional questions you may have.

1. What size inverter do you have?
2. What is the DC voltage of your battery bank?

3. Now divide the inverter's wattage by your battery voltage; this will give you the maximum current for your cables.

Example Calculation:

Current (Amps) = Power (Watts) / Voltage (Volt)

Consider 1500 Watt inverter connected to the 24V battery bank. (1500 W)/(24 Vdc)=62.5 A So, 62.5 A is the maximum current that the cable needs to support in order to properly provide the current to the inverter. The next higher size available on the table is 100A.

Use the above chart as a guide to determine which size cable will be best for your application.

In our example, we can see that 2/0 AWG cable would be appropriate.

NOTE: For distances over 10 feet, the voltage drop over the cables will occur due to resistance through the wiring. If you will need to run cables longer than 10 feet, it is recommended that you increase the cable size in order to compensate for voltage loss. If you are unsure about your application feel free to give us a call and we will be able to assist you in finding the right cable.

Step 30: Sizing of Fuses / Breakers

Fuses and circuit breakers are primarily used to protect the system wiring from catching fire or getting damaged if a short circuit occurs. They are not necessary for the system to run properly, but it is recommended for safety purposes only.

There are three different locations where fuses or breakers must be installed:

1. Between the charge controller and solar panel

2.Between the charge controller and battery bank

3.Between the battery bank and inverter

You can add one more breaker at the inverter output.

DC Breaker / Fuses:

As per NEC, the DC fuse or breaker size can be determined as per the following equation:

Circuit ampacity = Short Circuit Current (Isc) X 1.56

Example-1:

A 315 Watt module with an Isc rating of 9.12A.

To calculate the fuse size required between the string and the charge controller, you take 9.12 x 1.56 = 14.7 and round up to the next trade size of 15A.

Example-2:

Fuse between the battery bank and inverter = (continuous Watts / Battery Voltage) x 1.56

A 1000W /12V inverter draws = 1000/12 =83.3A,

Circuit Ampacity = 83.3 x 1.56 = 130A, round up to the next standard trade size which will be 150A.

AC Breaker/Fuses:

AC Breaker is placed at the inverter output and the Outlet for AC appliance.

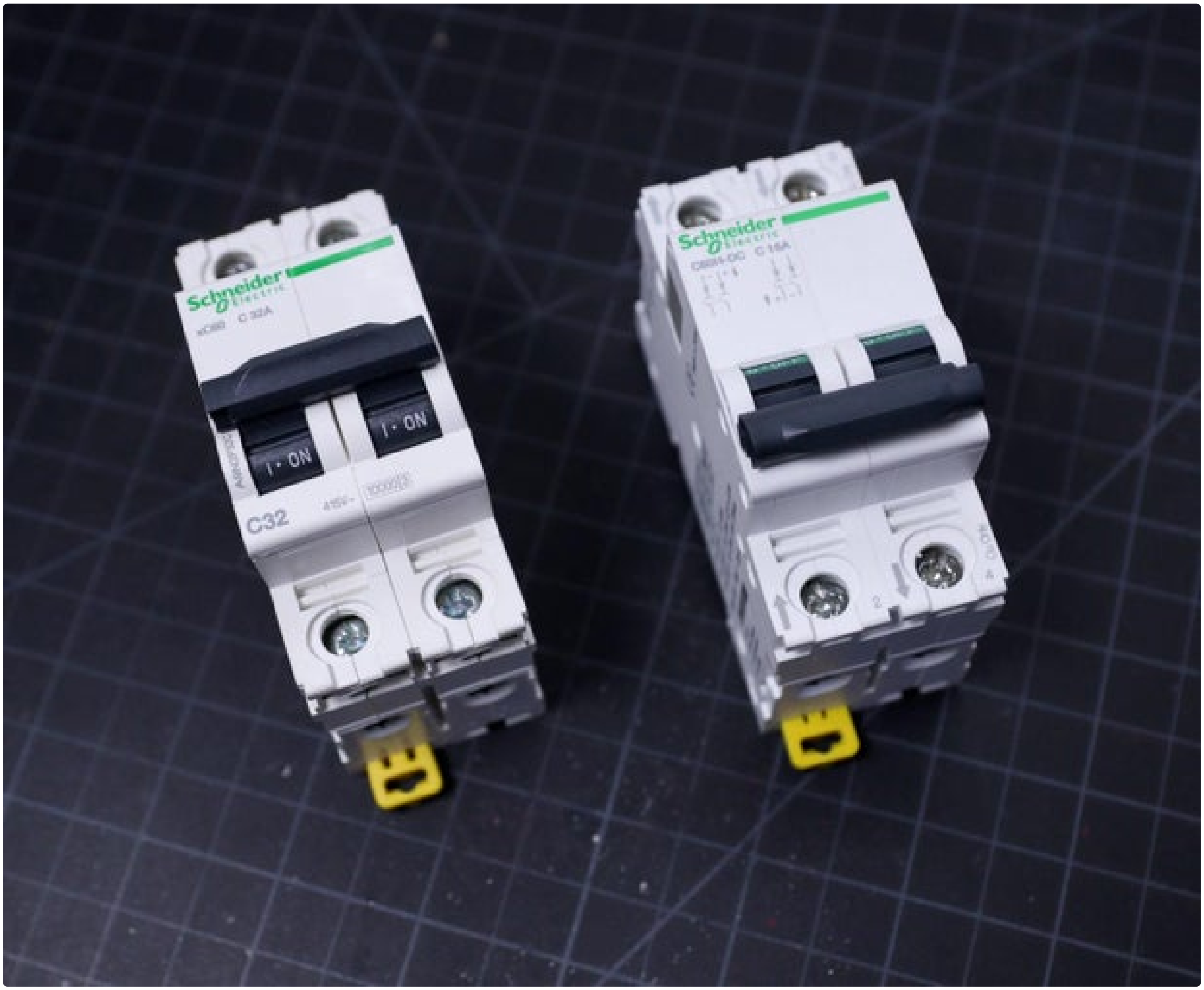
The above NEC ampacity formula also changes on the AC side of the circuit. Instead of 1.56, the multiplier is 1.25. And in place of the short-circuit current, you must use the maximum or continuous output current listed on the inverter specification sheet.

Circuit Ampacity = Inverter AC output current X 1.25

Example-3:

let's assume a 1500W inverter with an AC output of 6.5A max.

Circuit Ampacity = 6.5 x 1.25 = 8.12A, round up to the next standard trade size which will be 10A.



Step 31: Gather the Components and Tools

In the previous steps, we have already finalized the main components required for our Off-Grid Solar System. Now it is time to gather the components, I will always recommend buying all the components from a reputed brand. I have used the charge controller, inverter from EPEVER, solar panel from Waree, and battery from Luminous.

Apart from the 4 main components, there are few other components that are required for the off-grid system. They are listed below:

1. Solar Cables

1. Breakers / Fuses

2. DC Busbars / Fuse Box

4. MC4 Connectors

5. Cable Ties
6. Metering Device
7. Temperature Sensor

Tools Required:

To successfully install the off-grid solar system, you need a few basic tools like:

1. Wire Stripper
2. Crimping Tool
3. Plier
4. Screwdriver
5. MC4 Spanner
6. Spanners

After purchasing all the components and tools, we can move for the installation.


Pure Sine Wave Inverter
Solar Charge Controller
TRIRON series
PWM
SERIAL PORT TO ETHERNET CONVERT MODULE
Remote MeTer


JX-1601
JX-1301

Step 32: Wiring Diagram

Solar Panel :

The connection of solar panels depends on the maximum input voltage and current of the charge controller. MC4 connectors are used to connect the solar panels in series/parallel.

Battery Bank :

Battery banks should be wired to match your system voltage, which is the voltage allowed by your DC appliances or AC inverter. Copper cable or busbars are used to connect the battery in series and parallel.

Charge Controller:

The charge controller has 3 terminals: 1. Solar 2. Battery 3. DC Load.

You have to connect the wires from the solar panel, battery bank, and DC load to the respective terminal. During connection ensure the polarity is correct.

Inverter :

Connect the inverter input terminal to the battery bank. During connection ensure the polarity is correct.

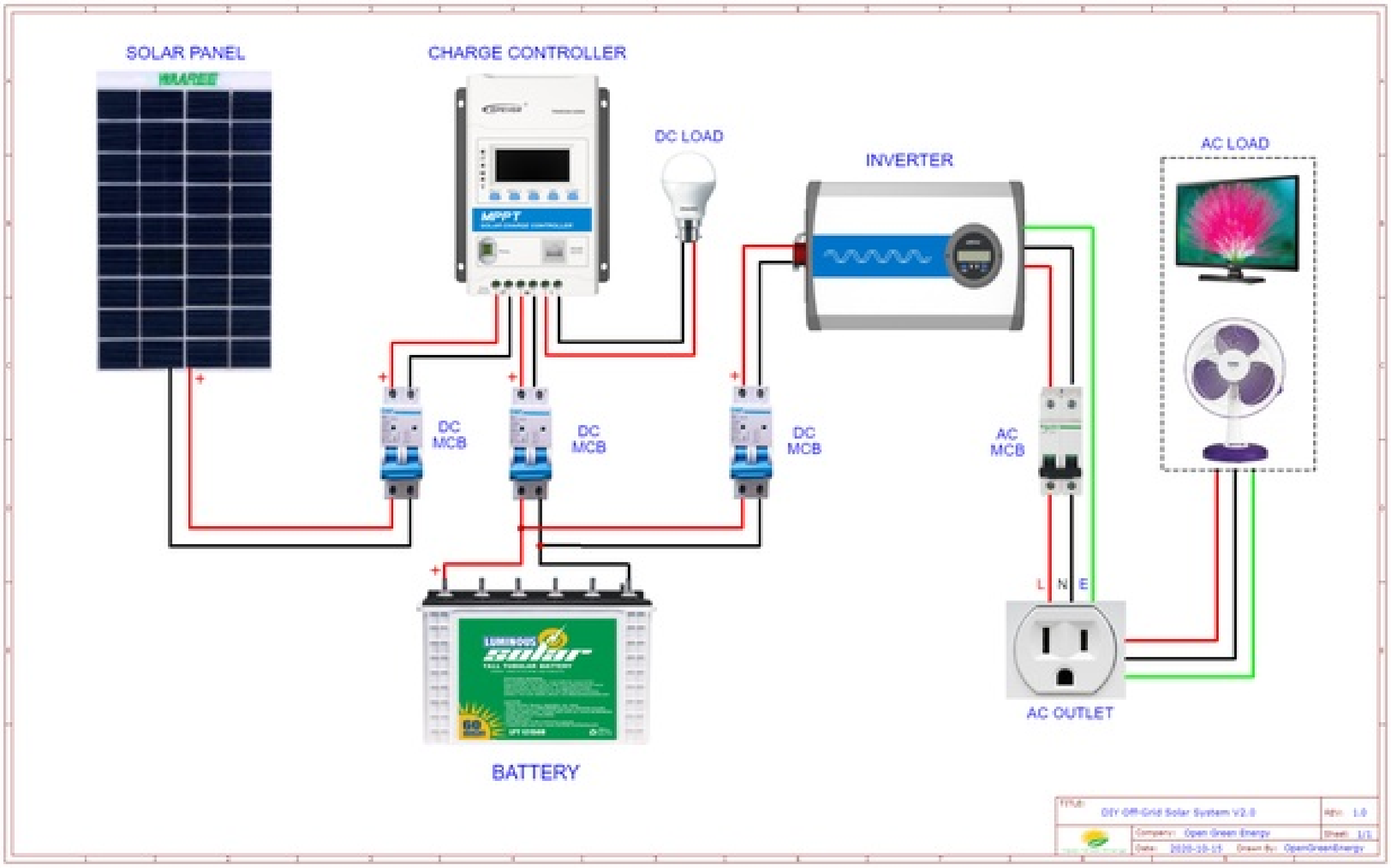
Protection :

Though the charge controller and inverter have inbuilt fuses for protection, you can put external fuses and breakers for more safety and reliability of the system. You can see the above picture for different locations of the breakers/fuses.

For a larger system, you need lighting protection. I will update you more about it later.

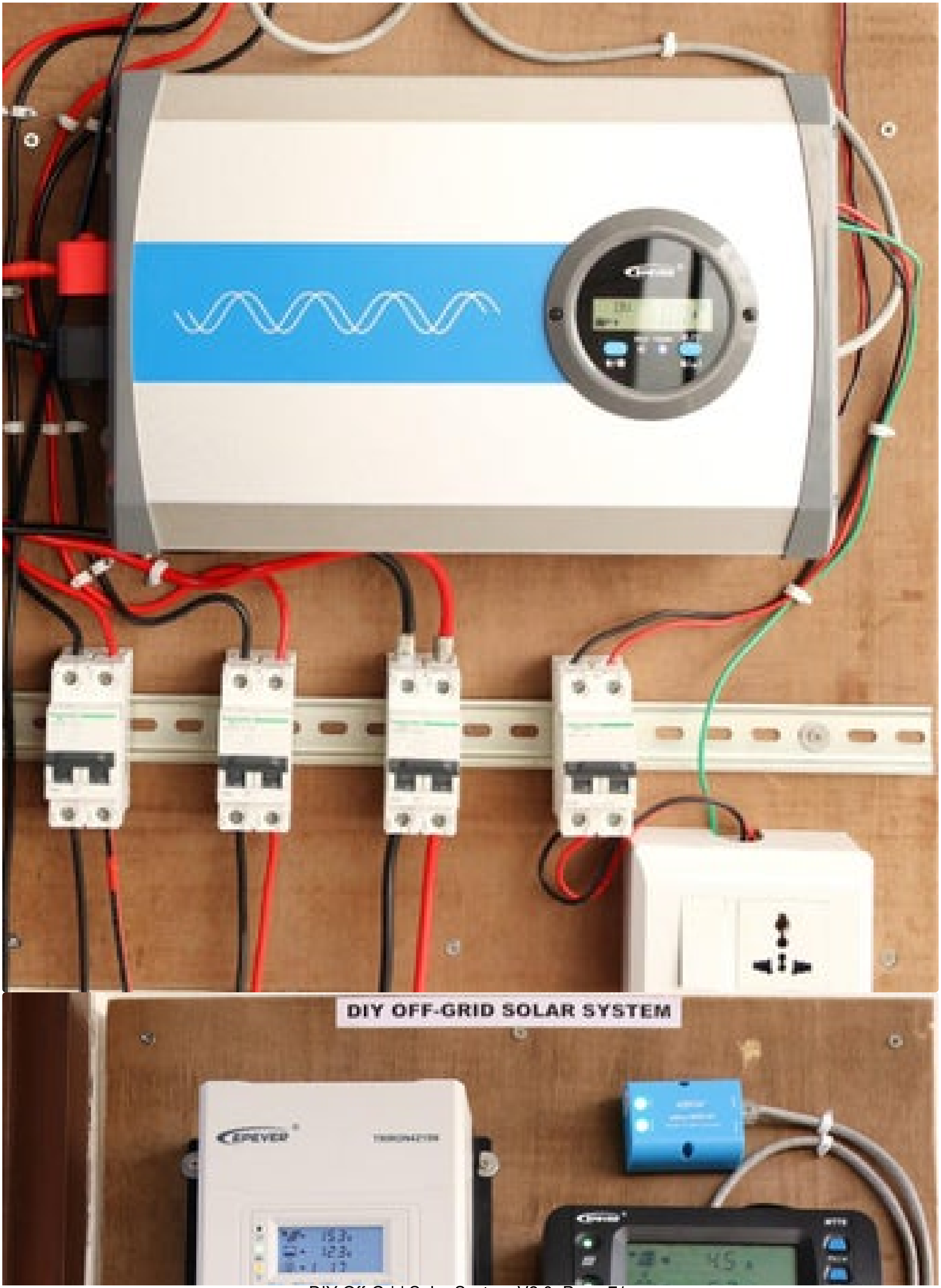
SAFETY :

It is important to note that we are dealing with the DC current. So the positive (+) is to be connected to positive (+) and negative (-) with negative (-) from Solar Panel to Charge Controller. If it gets mixed up, the equipment can go burst and may catch fire. So you need to be extremely careful when connecting these wires. It is recommended to use 2 color wires i.e. red and black color for positive (+) and negative (-). If you don't have a red and black wire you may wrap red and black tap at the terminals.



SOLAR PANEL
CHARGE CONTROLLER
DC LOAD
INVERTER
AC LOAD
DC MCB
DC MCB
DC MCB
AC MCB
L N E
AC OUTLET
BATTERY

DIY OFF-GRID SOLAR SYSTEM
MPPT


DIY OFF-GRID SOLAR SYSTEM

Download

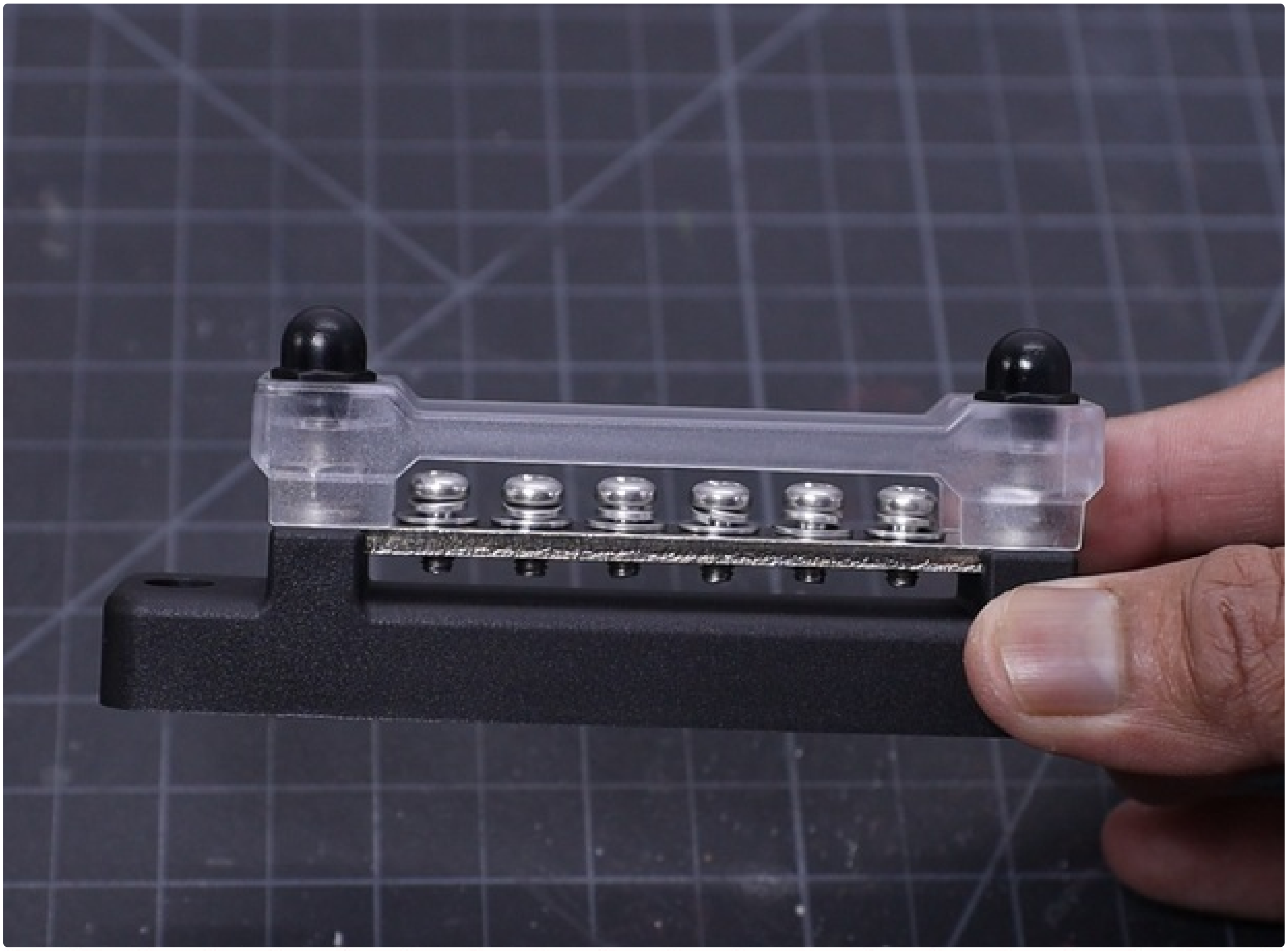
https://www.instructables.com/ORIG/FMR/V9FE/KHEUEQA4/FMRV9FEKHEUEQA4.pdf

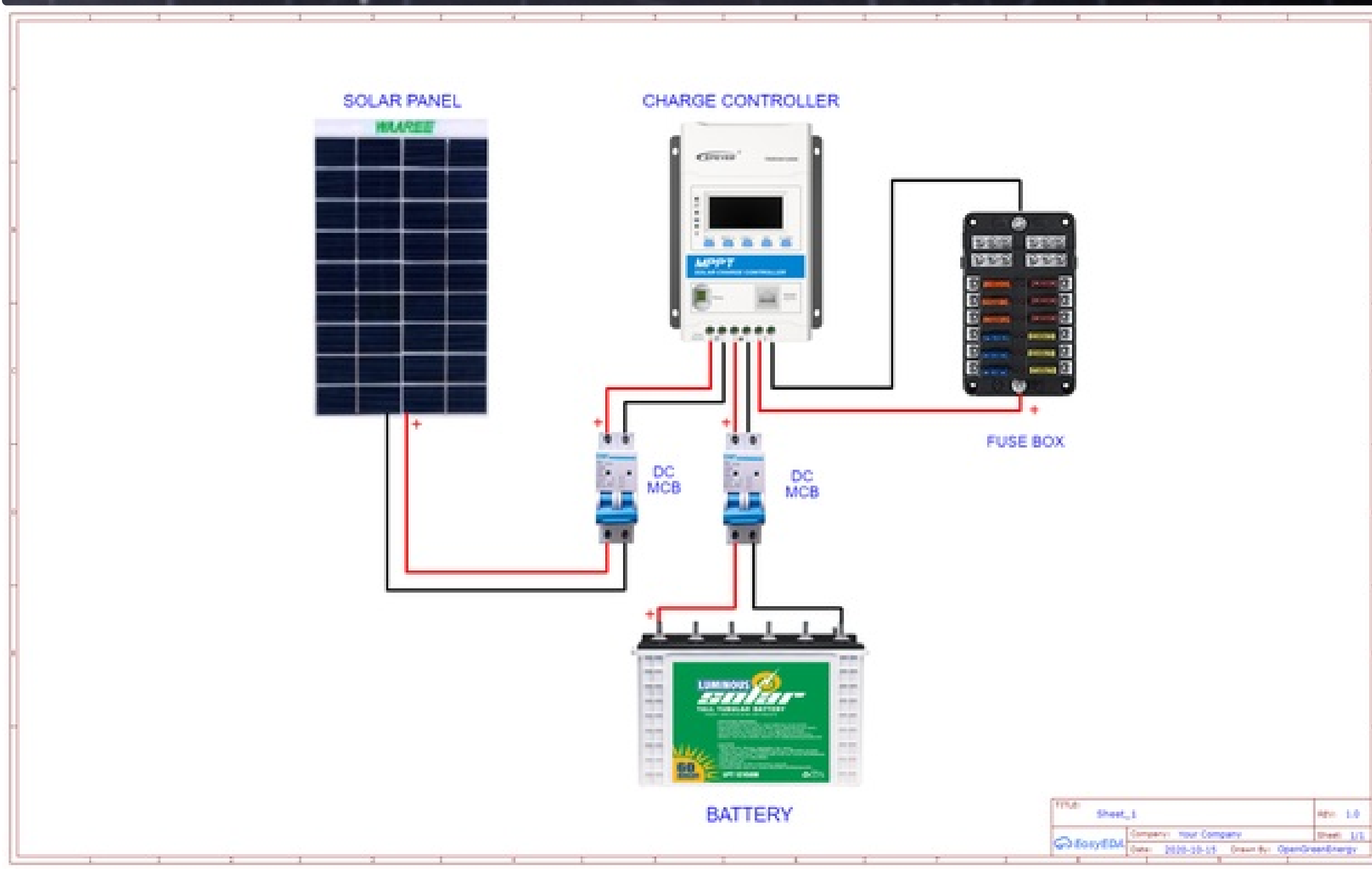
Step 33: Power Distribution

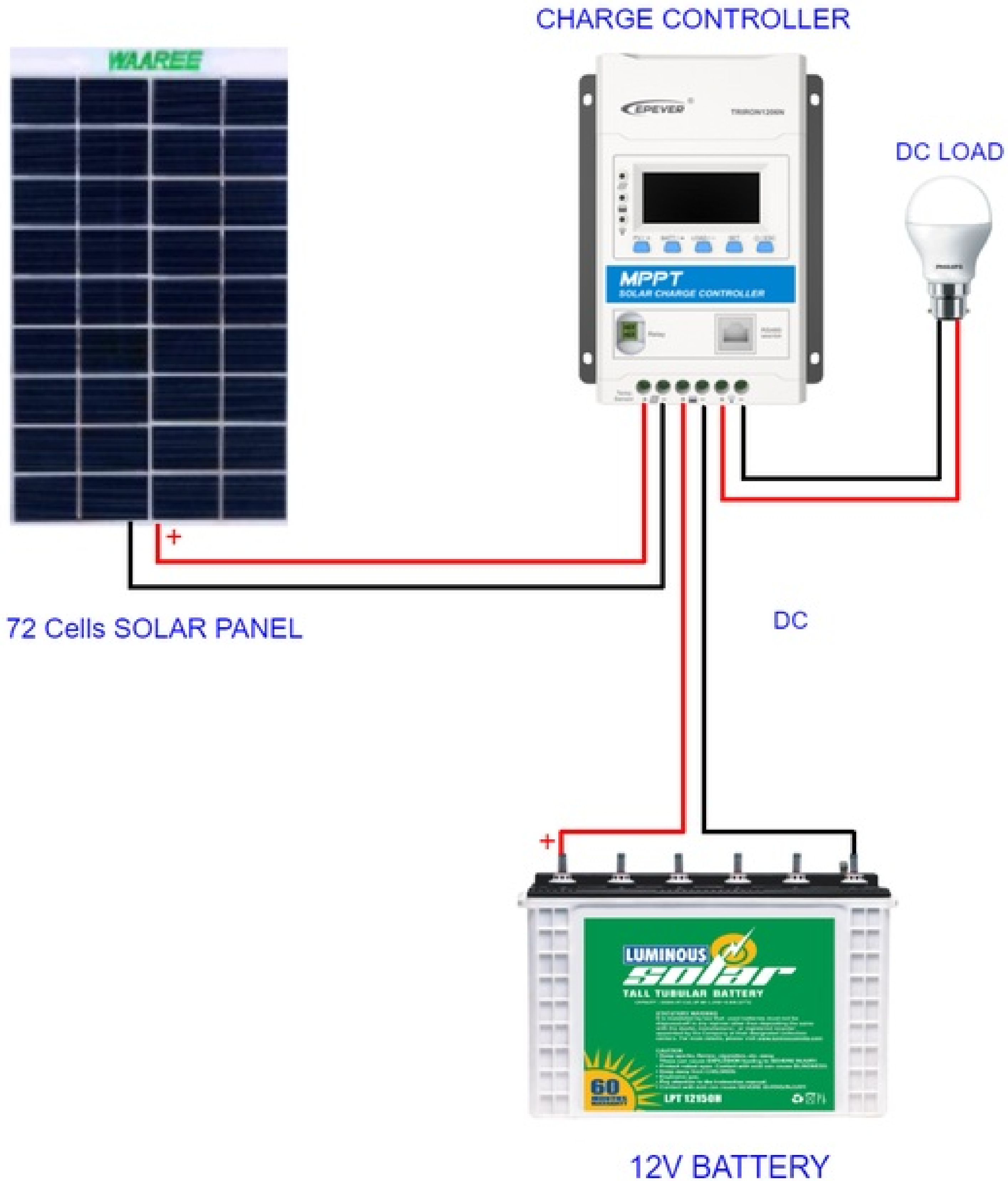
If you want to use a single DC load, you can connect directly to the Charge controller load terminal. Ensure the voltage rating of the load is matching with the load terminal voltage.

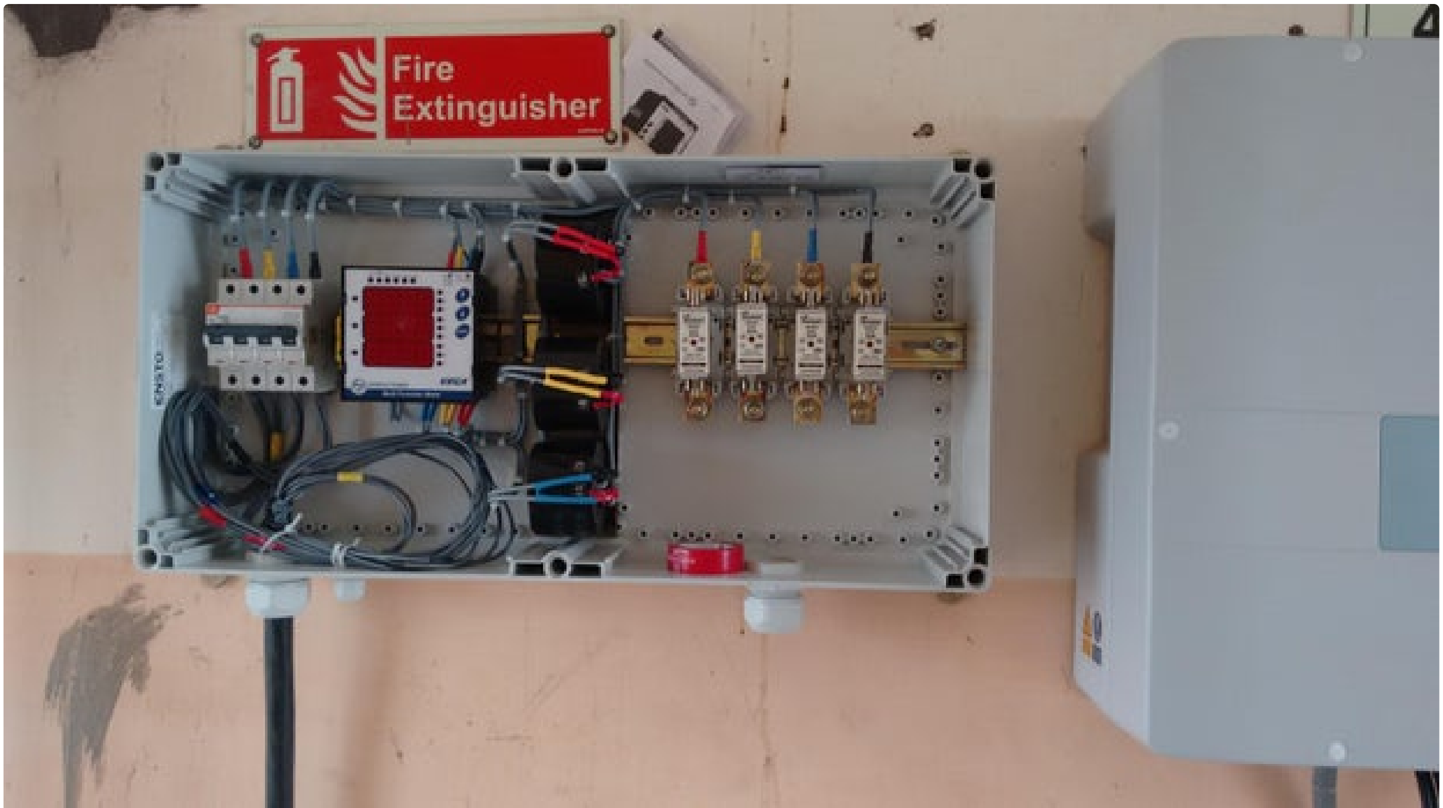
But If you want to run multiple DC loads at the same time, then you need a DC busbar or Distribution Box. Connect the busbar/ distribution box input to the charge controller load terminal and connect the loads to the output terminals of the distribution box.

Note: The total load current shall not cross the maximum limit of the charge controller load terminal. If the load current exceeds the charge controller load terminal limit, you have to connect the busbar/distribution box directly to the battery.




SOLAR PANEL
CHARGE CONTROLLER
DC
MCB
DC
MCB
FUSE BOX
BATTERY


CHARGE CONTROLLER
WAAREE
EPEVER
MPPT
SOLAR CHARGE CONTROLLER
DC LOAD
+
72 Cells SOLAR PANEL
DC
+
LUMINOUS
solar
TALL TUBULAR BATTERY
12V BATTERY



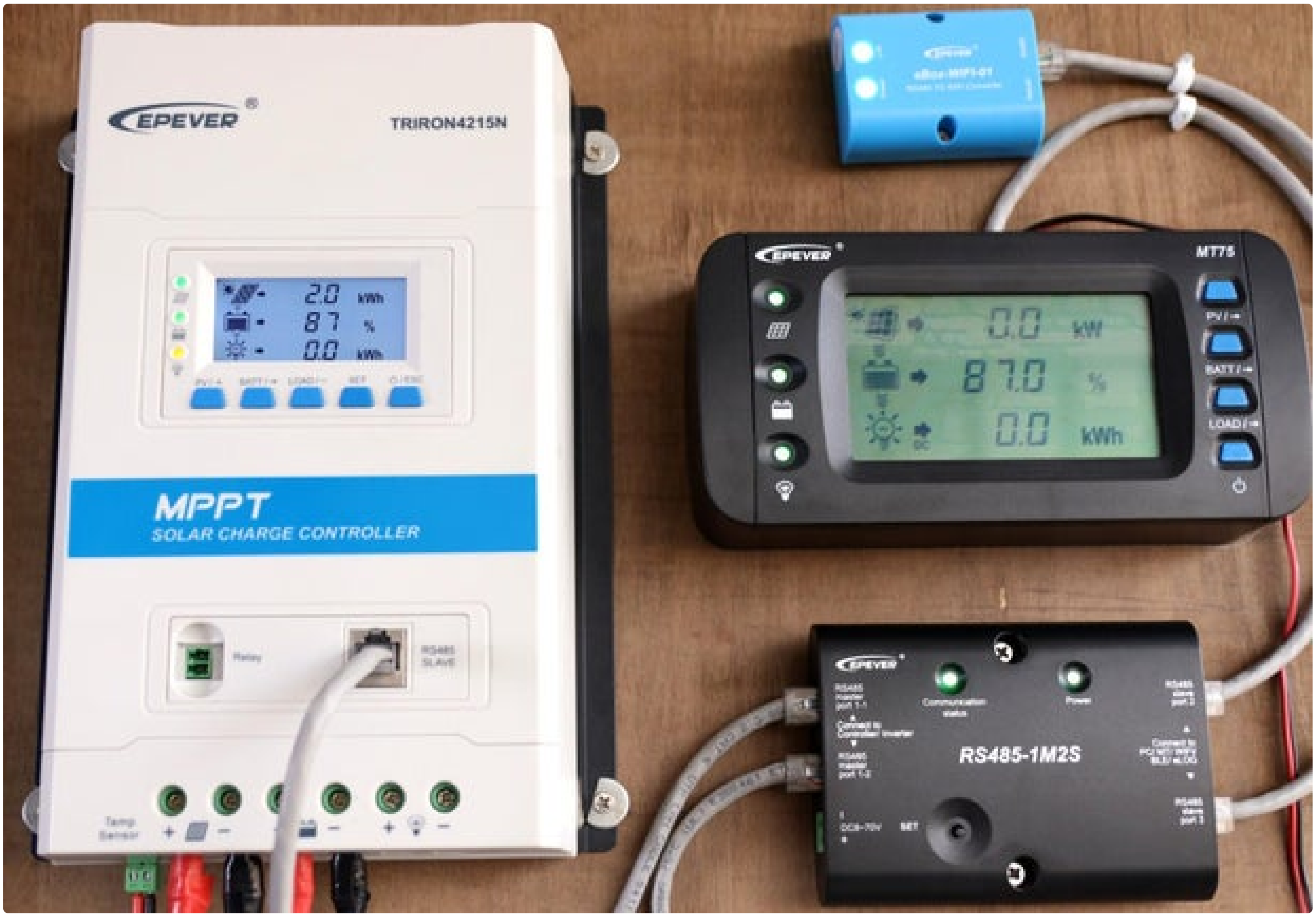
Step 34: Metering and Data Logging :

If you are interested to know how much energy is produced by your solar panel or how much energy is consumed by the appliances you have to use meters. Besides this, you can monitor the different parameters in your off-grid solar system by remote data logging.

Most of the good charge controller and Inverter have their inbuilt LCD display to monitor the parameters. Besides this, you can monitor the same parameter by using a remote meter or WiFi adapter.

In this project, I have used an Epever TRIRON Series MPPT charge controller and an IPower-Plus Series Inverter both of which have an LCD display for monitoring. Apart from this, there is provision for remote monitoring through the RJ45 communication port. For remote monitoring, I have used a remote meter MT75 and eBox-WIFI-01.

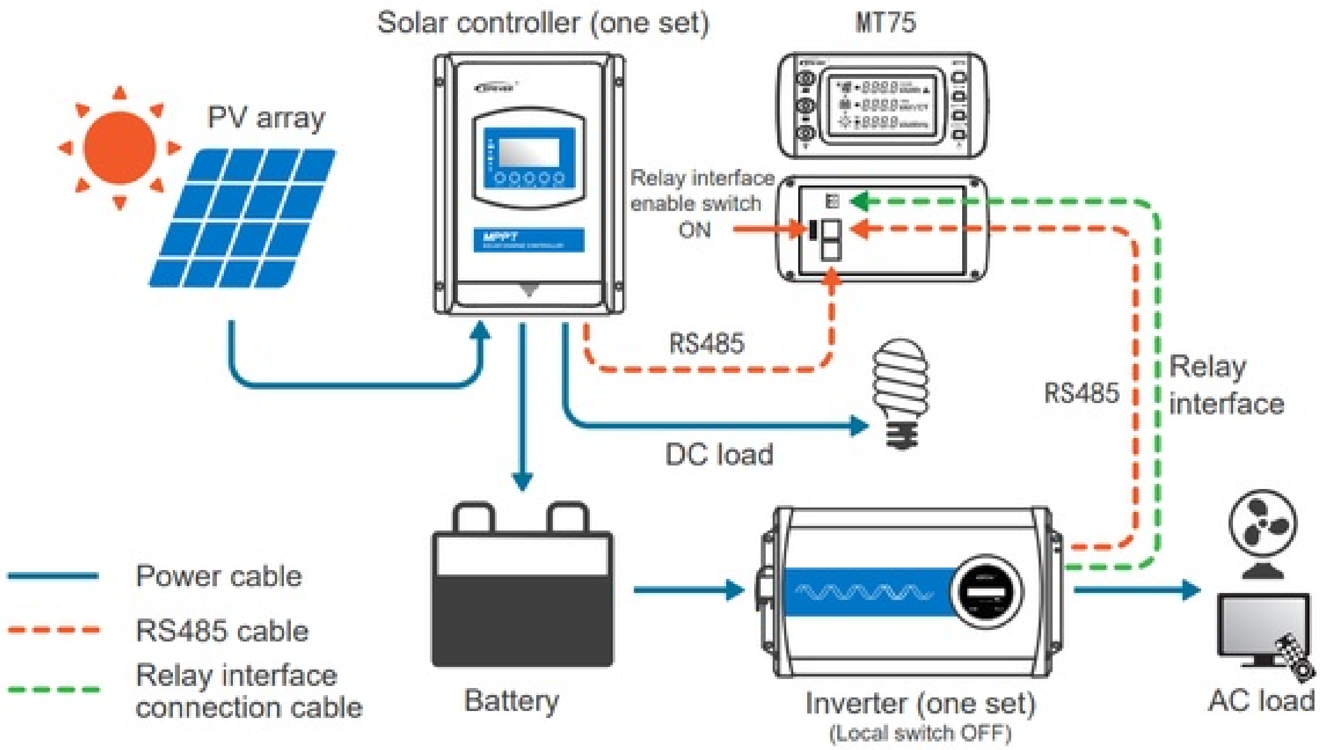
You can follow the above wiring diagram to connect the MT75 and eBox-WiFi.

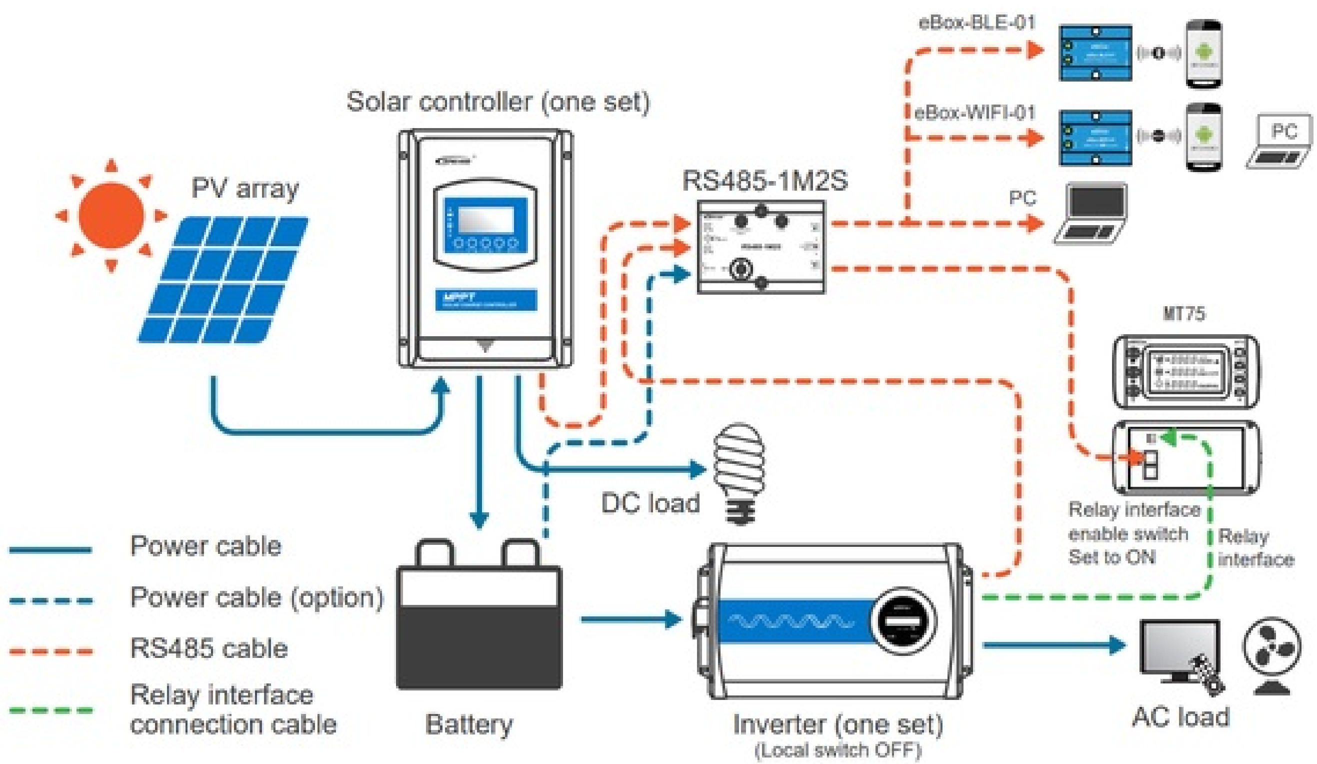



EPEVER
TRIRON4215N
MPPT
SOLAR CHARGE CONTROLLER
Relay
RS485 SLAVE
Temp Sensor
MT75
Controller
Real Time Monitoring
Device Settings
Battery Settings
Load Settings
Read
Send


EPEVER
TRIRON4215N
MPPT
SOLAR CHARGE CONTROLLER
MT75
Real Time Details


EPEVER
TRIRON4215N
MPPT
SOLAR CHARGE CONTROLLER
Relay
RS485 SLAVE
Temp Sensor
MT75
RS485-1M2S
Real Time Details
Solar Panel
Battery
Load


Solar controller (one set)
MT75
PV array
Relay interface
enable switch
ON
RS485
RS485
Relay
interface
DC load
Power cable
RS485 cable
Relay interface
connection cable
Battery
Inverter (one set)
(Local switch OFF)
AC load


eBox-BLE-01
eBox-WIFI-01
PC
Solar controller (one set)
RS485-1M2S
PC
PV array
MT75
DC load
Relay interface
enable switch
Set to ON
Relay
interface
Power cable
Power cable (option)
RS485 cable
Relay interface
connection cable
Battery
Inverter (one set)
(Local switch OFF)
AC load

Step 35: Battery Temperature Monitoring

Why Temperature monitoring is Required?

The battery's chemical reactions change with temperature. As the battery gets warmer, the gassing increases. As the battery gets colder, it becomes more resistant to charging. Depending on how much the battery temperature varies, it is important to adjust the charging for temperature changes. So it is important to adjust charging to account for the temperature effects. The temperature sensor will measure the battery temperature, and the Solar Charge Controller uses this input to adjust the charge set point as required.

I have used a remote temperature sensor for measuring the battery temperature. Connect it to the temperature port given in the charge controller.

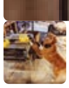
Step 36: Conclusion

I have shared my knowledge gather over the past few years, I hope it will be useful for all. If you like this Instructables, share it and like it.

I have participated in the Battery Powered Contest, please vote for me.

I will regularly update this Instructables, please keep in touch for more updated information on the Solar System.

Thank You!


Thanks for a great and informative article! Learned a lot!

Excellent!Very well explained, informative article I've ever read!!

Your presentation was great, but I did find one item that you might want to fix. In step 17 the diagram says all panels are 100 watts and 12 volts. The series connection should read 24 volts 100 watts output, not 200 watts output. Other than that it is one of the best instructables on solar power I have read.

Thank You so much.
In step-17, The series connection should read 24 volts 200 watts output, not 100 watts output.
Whether you connect panels in series or parallel, the wattage will be added but the voltage and current value will change depending on the configuration.

Example: The series connection of two 100W panels (Vmp = 17.4V and Imp=5.75A),
the current remains the same (5.75A) but the voltage will be doubled (34.8V).
Now the Power = Vmp x Imp = 34.8V x 5.75A = 200W

So basically what you are saying is that the wattage will be times the number of matching panels, whether in series or parallel.

Yes, you are correct.

This MUST be one of the best Instructables I have ever seen.
As a person who loves Green energy and has a Tesla Model X ready customised for when I can drive (in about 2 years time!!) I HAD TO VOTE for a BRILLIANT Instructable and will be definitely considering making this in the future.
At the min though,
I have a lot of Green Energy stuff in the pipeline...
You may even see some of this come onto my Instructables page.

And yet again,
Brilliant Instructable...

Luke Hayes

Thank You so much.
I have visited your Instructables page, you have very nice stuff.
Glad to know that you liked my project and considered it for future to do list.

I have to agree with the other's.... this was a well, thought out, presentation that provided both a nice "project build" but also an invaluable education in several of the areas presented. Great Job!!

Thank You so much.
Your words really motivate me.

A most useful and informative Instructable. Thank you so much for sharing your expertise!

Glad to know that it is useful for you. Than You !

Very well written and understandable. Thank you/

Glad you like it.

Very well done, sir. Very well done, indeed.

Thanks a lot.

I agree, very informative & clear details, better than I could ever do.
I will add the following that may be of interest...

1. Please consider the potential for fire propagation when mounting power products on wood board, it is worth doing a risk assessment.
2. The life of lithium battery is also dependent on how much time it is at full charge, not just the discharge depth cycle. I charge my LiFePo4 to only about 80~85%,(CC chg only) this ensurer's longer life (saving $$$).
3. Longer cables to inverter have higher inductance, this can put more ripple current stress on inverter capacitors shortening life. It is best to always keep short as possible.
4. Lithium battery like being less than full charge, this is ideal for some cloudy days when a full recharge is not possible. (lead battery don't like being discharged for extended time)
5. Lead battery has a fairly long tail current (slowly reducing Amps in CV chg mode), I charge my LiFePo4 battery with full current up to full (~80%), then stop & divert PV current to water heater.

Keep up the good work

Thank you so much.
I really appreciate your feedback for improvement. I will definitely consider it.

That is well done ! From scope, organization, graphics, grammar and spelling to system design, completeness and safety. I've never voted for contests but I have for this one !

Thank you so much. Your vote means a lot to me.

Amazing instructable! Really hoping to take advantage of all this knowledge some day.

One minor point: step 13, section 1 states that panels on the equator are more efficient due to proximity to the sun. While they are closer at noon than (for example) a panel at either pole, the difference is only the radius of the earth. Compared to an AU, that radius is extremely small. The theoretical reduction in power from a polar panel would be less than 0.01% (Can someone check my math?). I think the other reasons you stated are much more applicable.

Again—amazing post! Probably the best one I've seen ever!

Thank You So much.

Très bien fait bravo de la part d un ancien électricien de 72 ans , dommage que le pdf soit en anglais . je vous remercie de ce beau travaille cordialement Japhret

Thank You so much

Just wow. You are a born teacher my friend (I am an elementary school teacher so I know a good one when I see it!). I'm about to buy land and build on it and thought solar might be the way to go on a workshop. Alas, the land is way up in the snowy north and does not get enough sun to make this feasible.
But still, I'm bookmarking your page...
Well done, you got my vote!

Thank You so much. Your vote means a lot to me.
I really wanted to know the feedback about my article so that I can write a DIY book on this topic in the future.

This is one of the most informative, well written instructables I've read. You explained each part of the process and the different types of equipment so well! I had solar panels installed on my house a couple of years ago; however, in the state of Virginia we are not allowed to go completely solar or have any extra energy go back to the grid as a credit.

We are planning to sell within the next few years and build a new house on some land so

hopefully we'll be able to install our own on the new house.

Thanks for such information!

My pleasure!
I hope my article may help you during installation of your new house.

Very very good. thanks to share it

Thank You so much.

Hello,
first of all, a very good instructable.
But I wouldnt use the charge controller you use, bcs. the PV voltage is only 100V. For 4 Panels in series, you need at least 150V. Second, the controller is only up to 24V batterys, 48V is better I think.
The Inverter is also not so good, with no load it sucks 0,6A, this is 29W! I think too much.

Thank You!
Can you share the Specifications of your panel and charge controller ?

Great tutorial with to the point instructions. The steps are explained clearly and it is well documented. Thank you for your time to construct this instructable and for sharing. It assisted me tremendously.

Thanks a lot.
Glad to know that my article is helpful to you.

I really wanted to know the feedback about my article so that I can write a DIY book on this topic in the future.

Turely amazing work and excellent presentation.

Thank You.

Excellent Instructable! You've made this topic much more accessible for people new to the area of solar energy for individual use.

Thanks a lot.
I really wanted to know the feedback about my article so that I can write a DIY book on this topic in the future.

Excellent instructions, very detailed! I have a solar system installed on my pickup truck. I have been monitoring battery voltage at least every 15 minutes (sometimes every 10 seconds when driving). After years of evaluating the data, it turns out, for my application (testing multiple cellular/GPS tracking devices) a 100W panel was sufficient but my battery capacity was too low (85 A/Hr). Previous truck had two 100W panels but to weather bad weather of 4 days of rain / no sun, there is plenty of sun here in Texas to keep the batteries charged. After some consideration I changed to two 85 A/Hr batteries in parallel and no longer have issues. I like your approach as it is more scientific, informative, and covers all of the safety factors from wire size, fusing, DC power distribution and even AC fusing.

Excellent article!

Thank You so much for your appreciation.

Congratulations for what you do.
This DIY Off-Grid Solar System is really well explained.
It is simple and efficient
And what's more, it's affordable.

Thank you

Thank You so much.
Your words mean a lot to me.

One of the best instructables I have ever come across. You make DIY solar so easy to follow, I will be using your info and system. many many many thanks

Thank You so much. Your words mean a lot to me.
I have tried to make things simpler so that anyone can follow easily.

Nice work. A well laid out system and proper components for the right application. I have inspiration for my current system and now need to make changes, thank you for teaching the right way. Semper FI

Thanks a lot.
Glad to know that my article is helpful to you.
I really wanted to know the feedback about my article so that I can write a DIY book on this topic in the future.

Excellent article. Complete information in one place. Thank you for sharing.

Thank You!

Amazing article !! Really in depth !!

Thank you sharing your niche knowledge on this forum :)